

Training Course

Schloß Dagstuhl

in

Biomedical Ontology

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# Experience in Aligning Anatomical Ontologies



*Olivier Bodenreider*

Lister Hill National Center  
for Biomedical Communications  
Bethesda, Maryland - USA

# Acknowledgments

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## ◆ Songmao Zhang

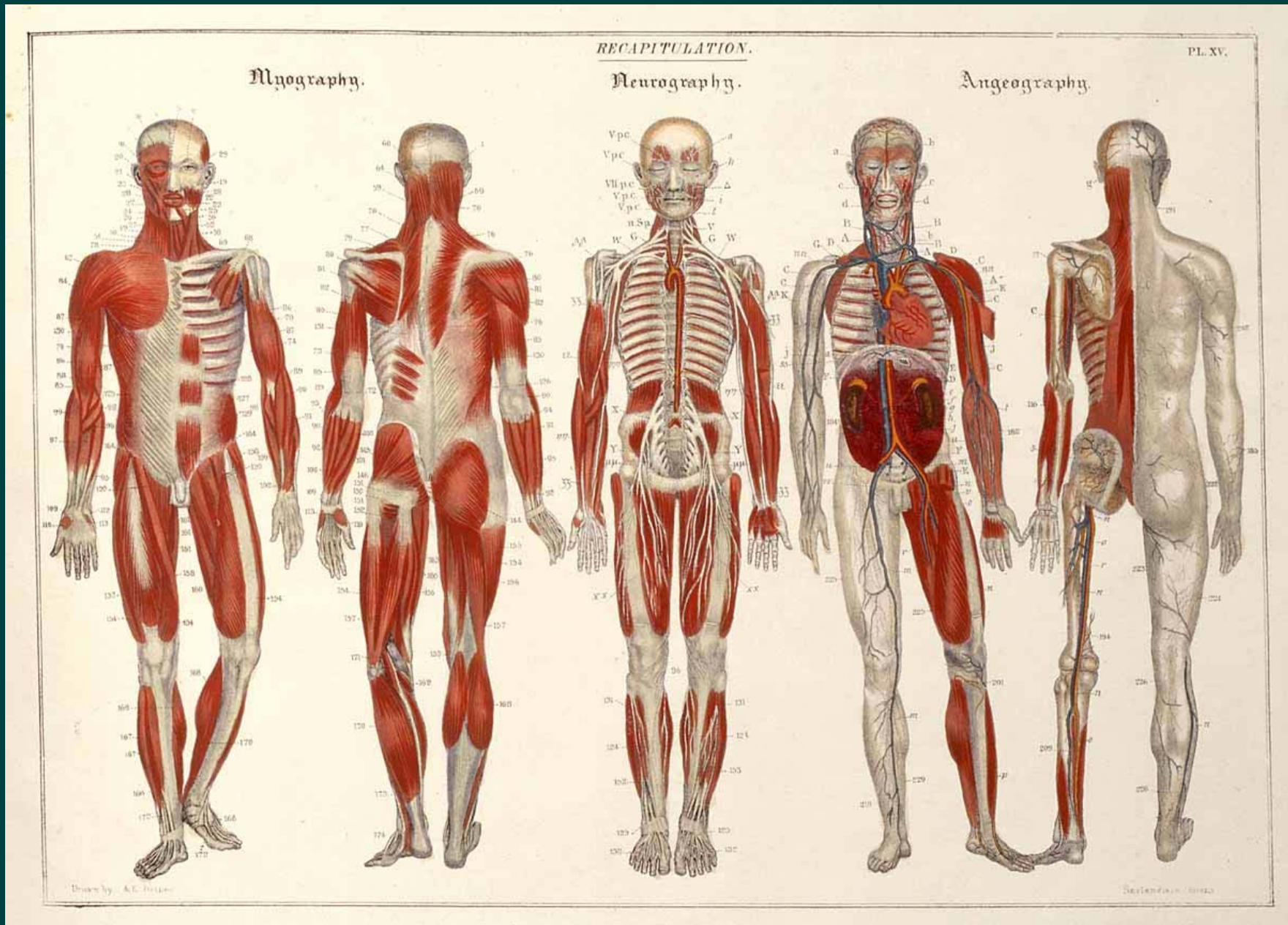
- *National Library of Medicine, USA*
- *Academy of Mathematics and System Sciences, Chinese Academy of Sciences, P.R. China*



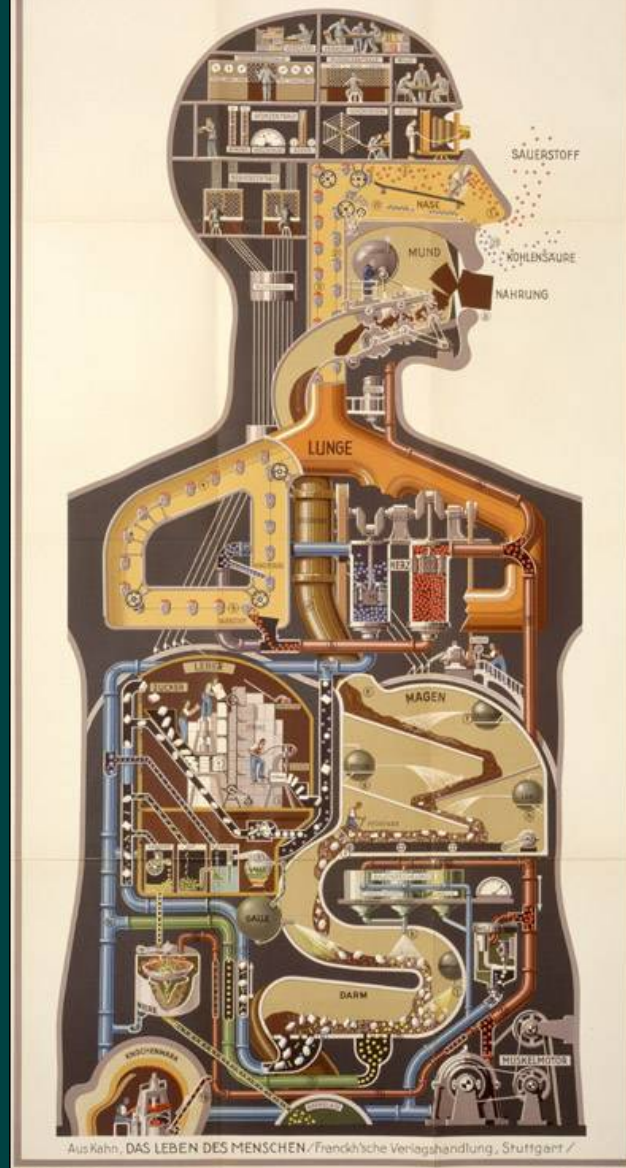
Govard Bidloo  
Gérard de Lairesse  
1690

<http://www.nlm.nih.gov/exhibition/dreamanatomy/index.html>



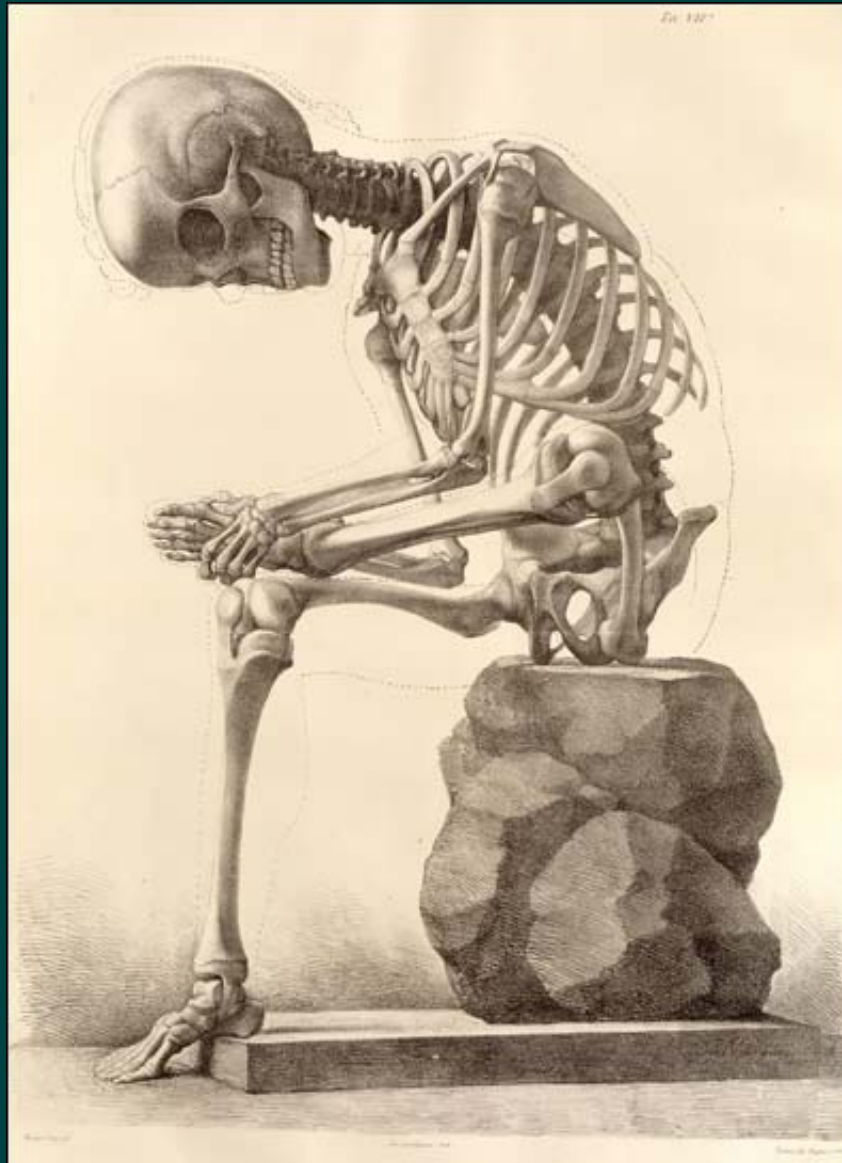


## Der Mensch als Industriepalast



Fritz Kahn  
1926

<http://www.nlm.nih.gov/exhibition/dreamanatomy/index.html>



Francesco Bertinatti  
Mecco Leone  
1837-39

<http://www.nlm.nih.gov/exhibition/dreamanatomy/index.html>

# Outline

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## ◆ Direct alignment

- Concepts (FMA-GALEN)
- Relationships
- Cross-species (Human-Mouse)

## ◆ Indirect alignment through a reference ontology



# Aligning Anatomical Concepts using Lexical and Structural Methods



# Introduction

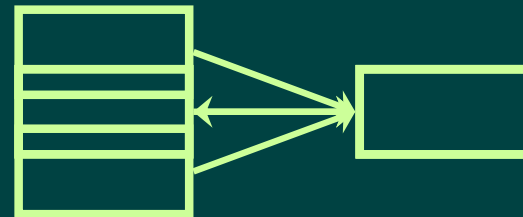
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## ◆ Different representations of one domain

- Formalism
- Structure
- Domain coverage

## ◆ Various approaches for comparing representations

- Merging
- Transformation
- Alignment



# Introduction

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## ◆ Objective

- Aligning two representations of anatomy
  - Foundational Model of Anatomy
  - GALEN common reference model
- Beyond lexical comparison
- Investigating reasoning capabilities

## ◆ Related work

- P. Mork, et al., Challenges in precisely aligning models of human anatomy using generic schema matching

Noy NF. Tools for mapping and merging ontologies. In: Staab S, Studer R, editors. Handbook on Ontologies: Springer-Verlag; 2004. p. 365-384



# Materials

# Two representations of anatomy

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## ◆ FMA

- Foundational Model of Anatomy
- University of Washington, 1994
- Conceptualization of the physical objects and spaces that constitute the human body

## ◆ GALEN common reference model

- Generalized Architecture for Languages, Encyclopaedias and Nomenclatures in medicine
- University of Manchester, 1991
- Development of a compositional and generative formal system for modeling all and only sensible medical concepts



# FMA and GALEN

	FMA	GALEN
Underlying data model	Frame-based structure Protégé-2000	Description logic GRAIL
Domain coverage	Anatomy	Medicine
Concepts	Pre-coordinated 59,422	Post-coordinated 25,192
Synonyms	28,686	No
Anonymous concepts	No	3,176
Hierarchical relationships	<i>is-a, part-of</i> (6)	<i>is-a, part-of</i> (26)
Multiple inheritance	Yes	Yes
Associative relationships	Yes	Yes

# Methods

# Alignment steps

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## Lexical alignment

- Step 1: Acquiring terms
- Step 2: Identifying anchors (i.e., shared concepts) lexically

## Structural alignment

- Step 3: Acquiring (explicit and implicit) semantic relations
- Step 4: Identifying anchors structurally



# Step 1: Acquiring terms

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## ◆ Extracting concept names

### ● FMA

#### ■ Preferred concept names

– *Uterine tube*

#### ■ Synonyms

– *Oviduct*

### ● GALEN

#### ■ Non-anonymous concept names

– *RoundLigamentOfUterus*

#### ❖ Not considered: anonymous concepts

– *(BodyStructure which < HasDivision Muscle >)*



## Step 2: Identifying anchors lexically

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- ◆ Comparing two systems at the term level
  - Exact match
  - Normalization
- ◆ Preferred concept names and synonyms
- ◆ Anchors (*i.e.*, shared concepts)
  - FMA: *Fibularis tertius*  
(synonym: *Peroneus tertius*)
  - GALEN: *Peroneus Tertius*

# Step 3: Acquiring semantic relations

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## ◆ Semantic relations

- $\langle concept_1, relationship, concept_2 \rangle$
- Hierarchical relationships: *is-a* and *part-of*
  - $\langle Arm, part-of, Proximal\ segment\ of\ upper\ limb \rangle$

## ◆ Extracting the explicit relations

## ◆ Acquiring implicit knowledge

- **Complementing** missing inverse relations
- **Augmenting** relations embedded in concept names
- **Inferring** relations from a combination of relations

# Implicit knowledge Complementing

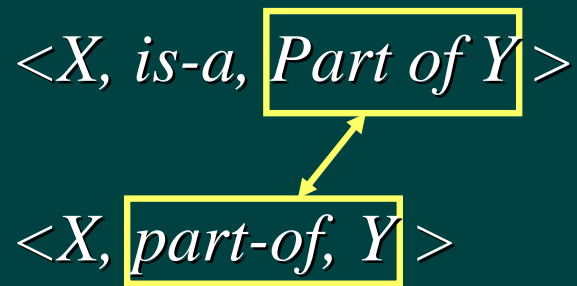
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- ◆ Inverse relationships
  - *is-a* and *inverse-is-a*
  - *part-of* and *has-part*
- ◆ Most *part-of* relations not represented bi-directionally
  - $\langle \textit{Arm}, \textit{has-part}, \textit{Humerus} \rangle$
- ◆ Complementing the inverse relations
  - $\langle \textit{Humerus}, \textit{part-of}, \textit{Arm} \rangle$

# Implicit knowledge Augmenting

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## ◆ Reification of *part-of* relationships



## ◆ Augmenting reified *part-of* relations

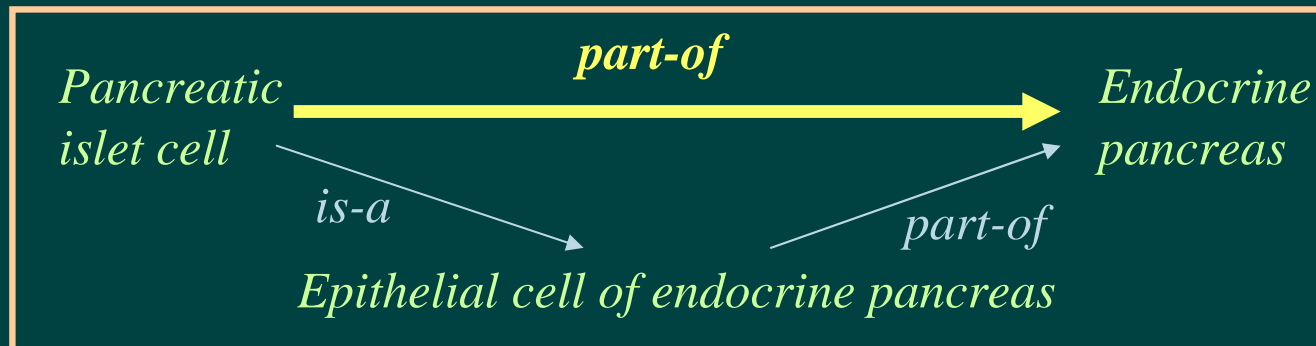
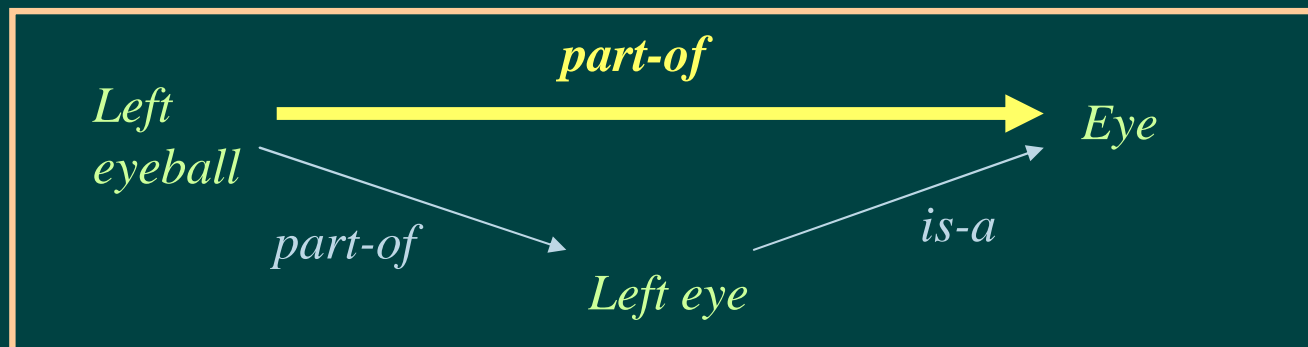
- Reified:  $\langle \text{Cardiac chamber}, \text{is-a}, \text{Subdivision of heart} \rangle$
- No explicit (direct or indirect) *part-of* relationships between *Cardiac chamber* and *Heart* in FMA
- Augmented:  $\langle \text{Cardiac chamber}, \text{part-of}, \text{Heart} \rangle$



# Implicit knowledge Inferring

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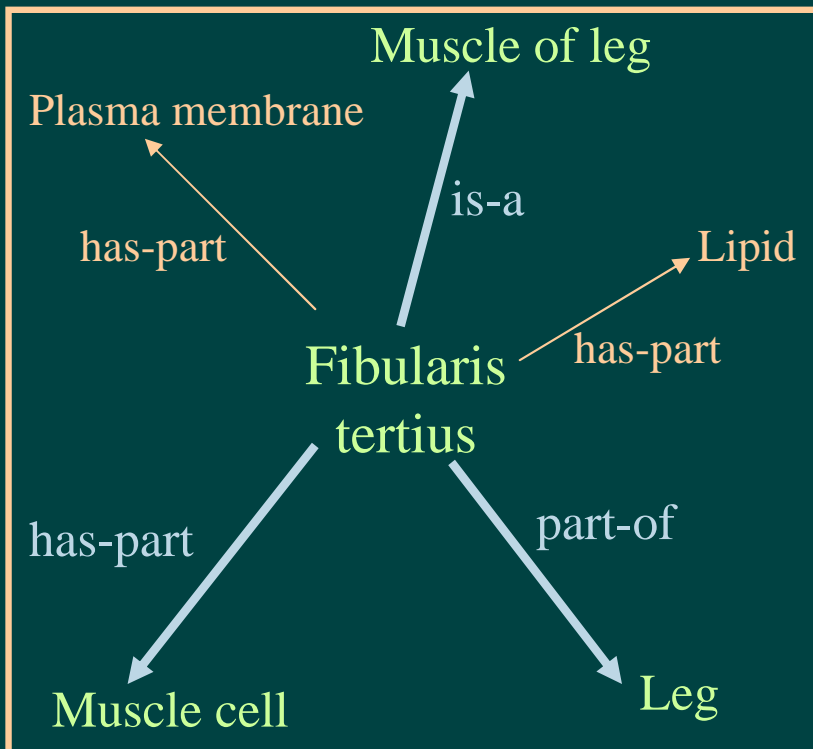
- ◆ Generating new inter-concept relationships by applying inference rules



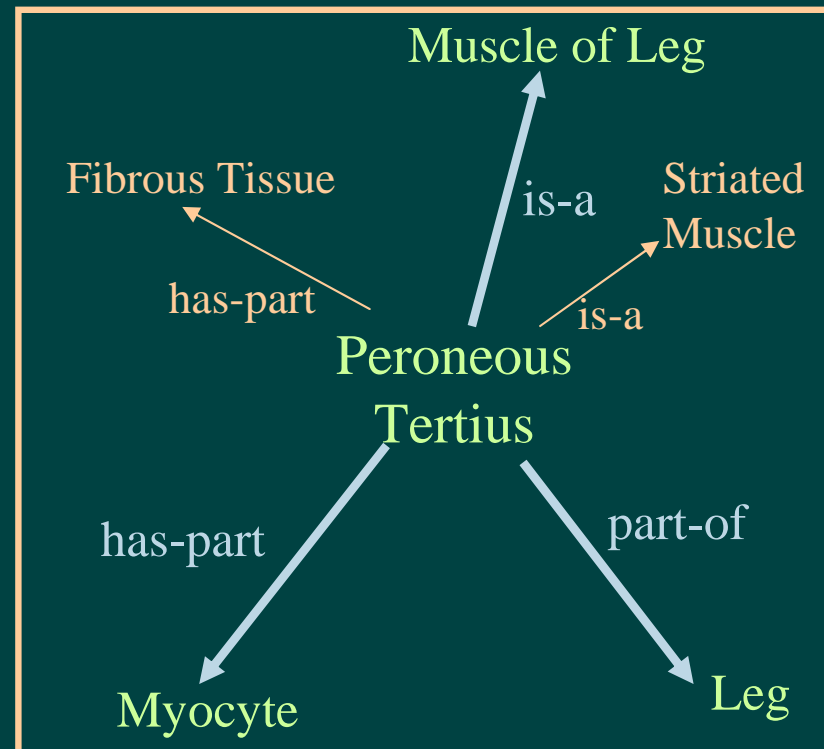
# Step 4: Identifying anchors structurally

## ◆ Structural similarity: common relations among anchors

FMA



GALEN



# Conflicts

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## ◆ Conflicts: semantic incompatibility between anchors

- Opposite type of links

- FMA: *Wall of heart has-part Apex of heart*

- GALEN: *Heart Wall part-of Apex of Heart*

- Disjoint top-level categories

- FMA: *Foot is-a Anatomical structure*

  **Disjoint**  
GALEN: *feet is-a Unit*

# Results



# Anchors identified by lexical alignment

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- ◆ 2,353 anchors
  - 4 % of FMA concepts
  - 9 % of GALEN concepts

# Semantic relations acquired

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Types of relations	FMA	GALEN
Explicitly represented	238,135	214,403
Complemented	104,754	107,689
Augmented	315,860	27,274
Inferred	5,172,668	1,661,824
Total	5,831,417	2,011,190

# Anchors identified by structural alignment

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No evidence
Positive evidence
Negative evidence

# Discussion

# Explicit vs. implicit knowledge

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- ◆ More positive structural evidence found for anchors
- ◆ Augmentation accounted for 74% of 523 anchors acquiring positive evidence
- ◆ More conflicting relations found for anchors

# References

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- ◆ Zhang S, Bodenreider O. *Aligning representations of anatomy using lexical and structural methods*. Proceedings of the First International Proceedings of AMIA Annual Symposium 2003:753-757.  
<http://mor.nlm.nih.gov/pubs/pdf/2003-amia-sz.pdf>
- ◆ Zhang S, Bodenreider O. *Knowledge augmentation for aligning ontologies: An evaluation in the biomedical domain*. Proceedings of the Semantic Integration Workshop at the Second International Semantic Web Conference (ISWC 2003) 2003:109-114.  
<http://mor.nlm.nih.gov/pubs/pdf/2003-iswc-semint-sz.pdf>

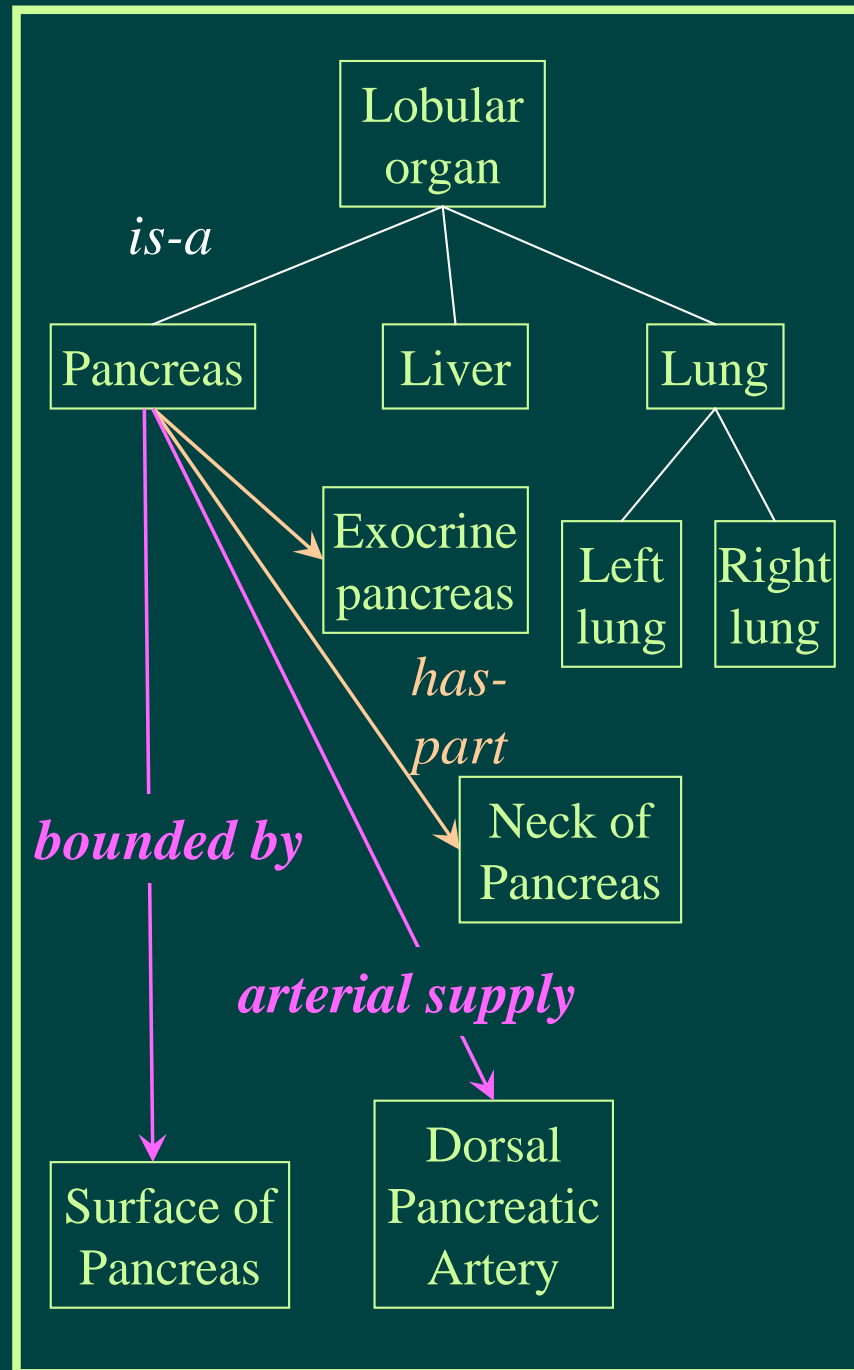


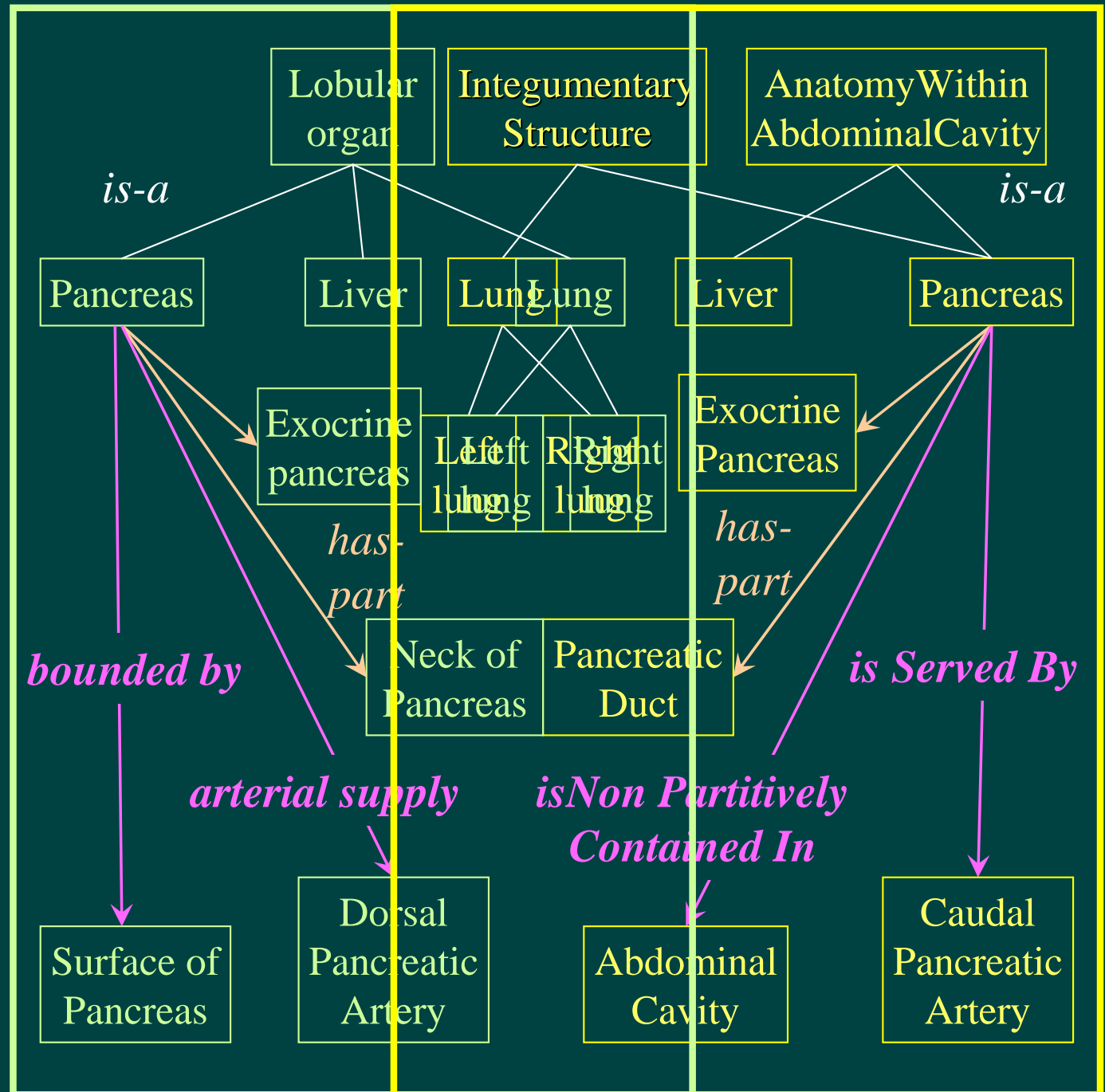
# References

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- ◆ Zhang S, Mork P, Bodenreider O. *Lessons learned from aligning two representations of anatomy*. Proceedings of the First International Workshop on Formal Biomedical Knowledge Representation (KR-MED 2004); 2004. p. 102-108.  
<http://mor.nlm.nih.gov/pubs/pdf/2004-krmed-sz.pdf>
- ◆ Zhang S, Bodenreider O. *Investigating implicit knowledge in ontologies with application to the anatomical domain*. Pacific Symposium on Biocomputing 2004: World Scientific; 2004. p. 250-261.  
<http://mor.nlm.nih.gov/pubs/pdf/2004-psb-sz.pdf>

# Comparing Associative Relationships among Equivalent Concepts across Ontologies





# Introduction

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- ◆ Few ontology merging / aligning tools deal with the issue of comparing associative relationships
- ◆ Our ontology aligning project
  - Two representations of anatomy
    - Foundational Model of Anatomy (FMA)
    - GALEN Common Reference Model
  - Aligning hierarchical relationships manually
  - Aligning concepts based on both lexical and hierarchical similarity

# Introduction

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- ◆ Objective: to identify equivalent expressions for associative relationships across ontologies
- ◆ Assumptions
  - Correspondence
    - between two relationships
    - between one relationship and a combination of relationships
  - Types of match
    - one-to-one
    - one-to-many
    - no match
  - Frequency of the correspondence

# Materials



# Two representations of anatomy

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## ◆ FMA

- Foundational Model of Anatomy
- University of Washington, 1994
- Conceptualization of the physical objects and spaces that constitute the human body

## ◆ GALEN common reference model

- Generalized Architecture for Languages, Encyclopaedias and Nomenclatures in medicine
- University of Manchester, 1991
- Development of a compositional and generative formal system for modeling all and only sensible medical concepts

# FMA and GALEN

	FMA	GALEN
Underlying data model	Frame-based structure Protégé-2000	Description logic GRAIL
Domain coverage	Anatomy	Medicine
Concepts	Pre-coordinated 66,879	Post-coordinated 52,006
Hierarchical relationships Inverses	<i>is-a, part-of</i> (8) <i>inverse-isa, has-part</i>	<i>is-a, part-of</i> (40) <i>inverse-isa, has-part</i>
Associative relationships	59 Some have inverses <i>branch of / branch</i> <i>input from</i>	562 Every one has inverse <i>isBranchOf / hasBranch</i> <i>isServedBy / serves</i>

# Methods

# Comparing associative relationships

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- ◆ NOT based on lexical similarity
- ◆ Based on previously identified equivalent concept pairs between FMA and GALEN
  - Share both lexical and hierarchical similarity
    - FMA: *Pancreas has-part Exocrine pancreas*
    - GALEN: *Pancreas has-part ExocrinePancreas*
  - Anchors (i.e., equivalent concepts across ontologies)
    - 2,604 pairs
    - 4% of FMA concepts and 5% of GALEN concepts

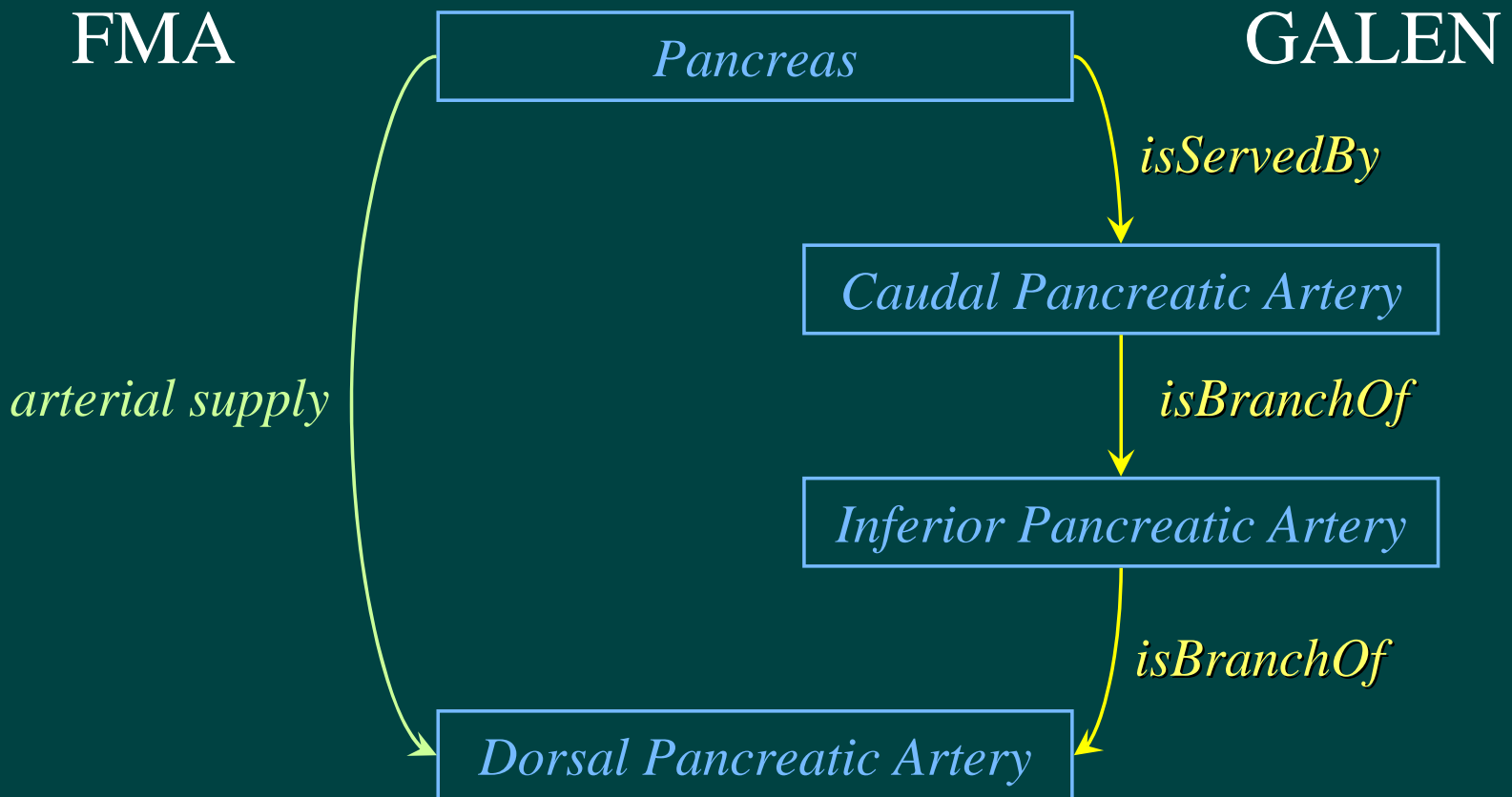
# Step 1 Acquiring associative relations

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- ◆ Associative relations: *concept<sub>1</sub> relationship concept<sub>2</sub>*
- ◆ Extracting the explicit relations
  - *Kidney isServedBy AutonomicNerveOfAbdomen*
- ◆ Complementing the missing inverse relations
  - *AutonomicNerveOfAbdomen serves Kidney*
- ◆ Augmenting relations embedded in concept names
  - Explicit: *Lateral cutaneous nerve of forearm*  
*X branch-of Y*  
*is-a Branch of musculocutaneous nerve*
  - Augmented: *Lateral cutaneous nerve of forearm*  
*X is-a Branch of Y*  
*branch of Musculocutaneous nerve*

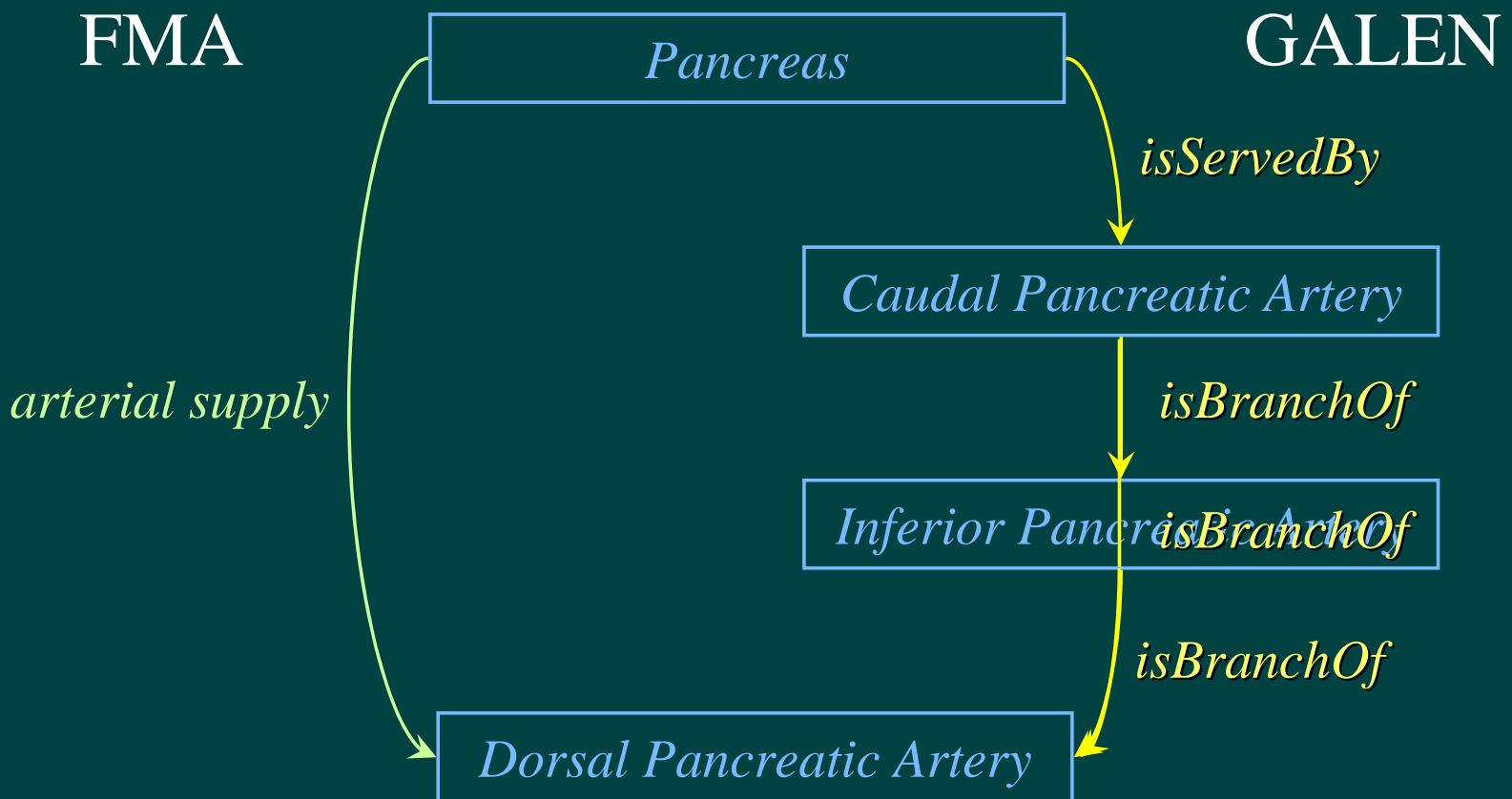
# Step 2 Identifying relationship patterns

## ◆ Search for inter-anchor path pairs



## Step 2 Identifying relationship patterns

- ◆ Create relationship patterns from path pairs





# Step 2 Identifying relationship patterns

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## ◆ Create relationship patterns from path pairs

- FMA: *arterial supply*  
GALEN: *isServedBy – isBranchOf*
- Direct and indirect relationship patterns
- Frequency of relationship pattern
  - $$\frac{\text{Number of path pairs sharing the pattern}}{\text{Number of all path pairs}}$$
  - Most frequent vs. accidental relationship patterns

# Results

# Associative relations acquired

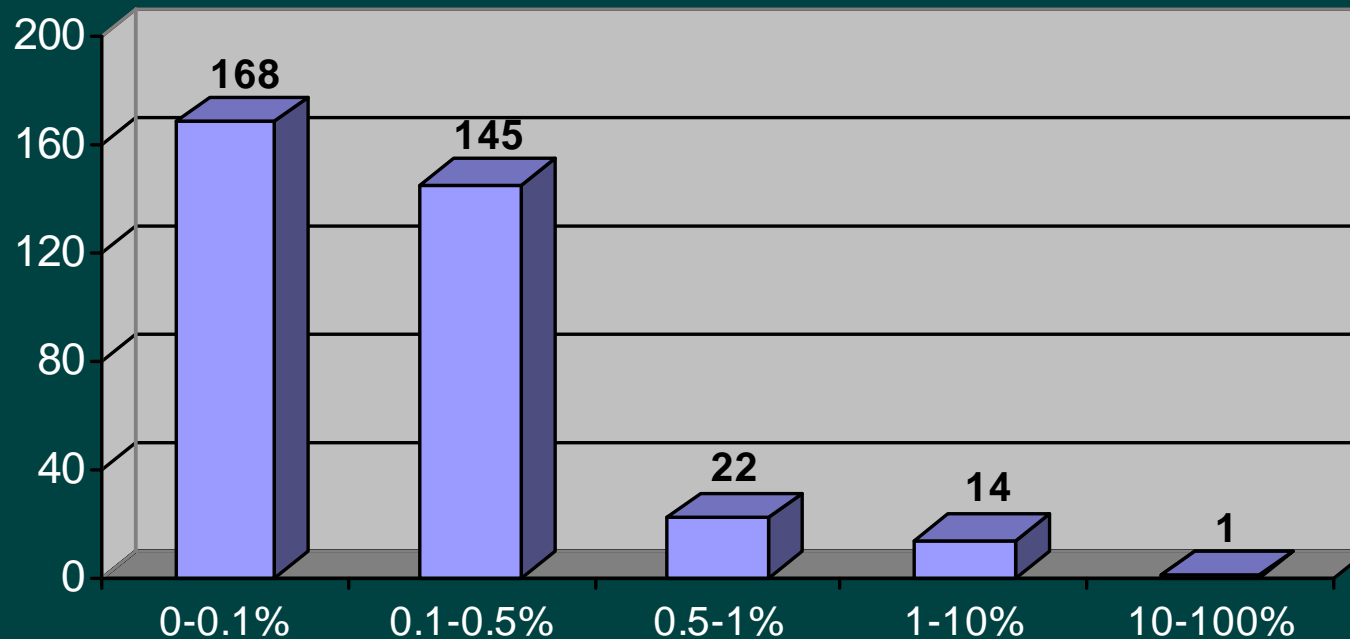
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Associative relations	FMA	GALEN
Explicit	18,688	288,732
Complemented	1,057	249,938
Augmented	1,838	108
Total	21,583	538,778
Between anchors	847	6,922

# Path pairs and relationship patterns identified

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- ◆ 4,070 inter-anchor path pairs
- ◆ 350 relationship patterns (47 direct and 303 indirect)



Frequency distribution of relationship patterns



# Examples of relationship patterns

FMA	GALEN	Frequency (N = 4,070)	
<i>part-of</i>	<i>isBranchOf</i>	518	13%
<i>branch of</i>	<i>isBranchOf</i>	310	8%
<i>tributary of</i>	<i>isBranchOf</i>	104	3%
<i>member of</i>	<i>is-a</i>	42	1%
<i>nerve supply</i>	<i>part-of – isServedBy</i>	16	0.4%
<i>part-of – contained in</i>	<i>isNonPartitivelyContainedIn</i>	10	0.25%
<i>contained in</i>	<i>boundsSpace – inverse-isa</i>	2	0.05%

# Multiple matches

FMA	GALEN	Frequency (N = 74)
<i>arterial supply</i>	<i>isServedBy</i>	18 24%
	<i>isServedBy – isBranchOf</i>	34 46%
	<i>isServedBy – part-of</i>	
	<i>isServedBy – is-a</i>	
	<i>isServedBy – inverse-isa</i>	
	Other combinations	22 30%

# Discussion



# Analysis of relationship patterns

Types of patterns	Number of patterns (N = 350)	Examples	Analysis
Associative corresponds to Associative	14    4%	F: <i>tributary of</i> G: <i>isBranchOf</i>	Equivalent associative relationships
Associative corresponds to Combination	303    87%	F: <i>arterial supply</i> G: <i>isServedBy – is-a</i>	Different levels of granularity or modeling choices
Associative and Hierarchical	33    9%	F: <i>bounded by</i> G: <i>has-part</i>	Not semantic equivalence

# Semantic vs. lexical correspondence

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## ◆ Semantically and lexically similar

- 3 cases
- {FMA: *branch of*, GALEN: *isBranchOf*}

## ◆ Semantically similar but lexically different

- 11 cases
- {FMA: *arterial supply*, GALEN: *isServedBy*}

## ◆ Semantically different but lexically similar

- 4 cases
- ~~{FMA: *bounded by*, GALEN: *isSpaceBoundedBy*}~~

# Limitations and future work

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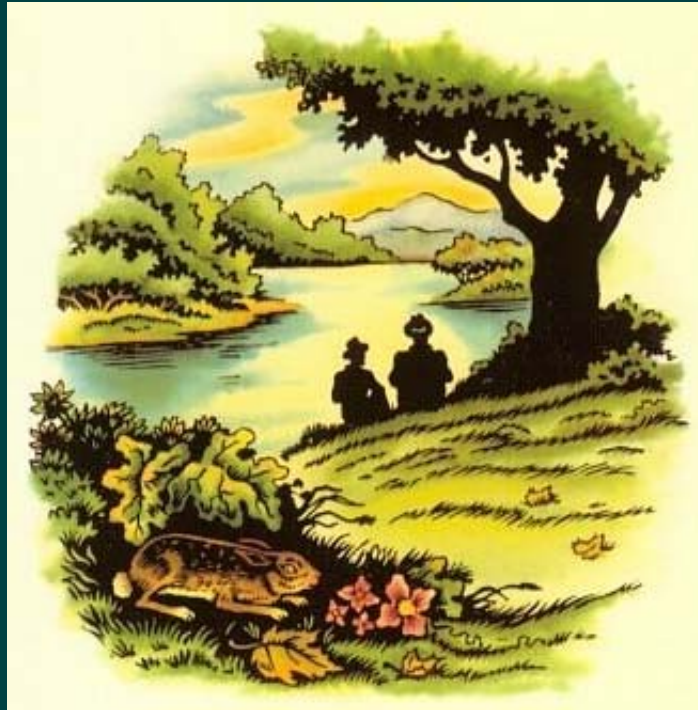
- ◆ Associative relationships do not exist in paths between anchors are not matched
  - 56% of FMA (e.g., *fascicular architecture*)
  - 84% of GALEN (e.g., *isPositionedDistalTo*)
- ◆ Anchors used for identifying equivalent relationships have not been fully validated
- ◆ Take advantage of the equivalent relationships to discover more equivalent concepts

# References

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- ◆ Zhang S, Bodenreider O. *Comparing associative relationships among equivalent concepts across ontologies*. Medinfo 2004:459-463.  
<http://mor.nlm.nih.gov/pubs/pdf/2004-medinfo-sz.pdf>





## Aligning Mouse and Human Anatomies

# Introduction

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- ◆ Anatomy is central to the biomedical domain
- ◆ Comparing functional information about genes across model organisms requires aligned anatomies
- ◆ Objective: to align two ontologies of anatomy
  - Mouse anatomy  
*Adult Mouse Anatomical Dictionary*
  - Human anatomy  
*Anatomy subset of NCI Thesaurus*
- ◆ Contribution to the caBIG project



# Materials

# Adult Mouse Anatomical Dictionary (MA)

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- ◆ Structured controlled vocabulary
- ◆ 2,404 concepts each identified by one name
  - *Head/neck, Adrenal artery*
- ◆ 259 synonyms
  - *Limb* has a synonym *Extremity*
- ◆ Directed acyclic graph
- ◆ Two relationships: *is-a* and *part-of*
- ◆ 38% concepts have no *is-a* relationship
  - *Knee part-of Hindlimb*
- ◆ 4% concepts have more than one *is-a* relationship
  - *Hand phalanx is-a Phalanx*  
*is-a Hand digit bone*



# NCI Thesaurus (NCI)

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- ◆ Standard vocabularies for cancer research
- ◆ Anatomy class
- ◆ Available in Ontology Web Language (OWL)
- ◆ 4,410 concepts, each having one preferred name
  - *Abdominal esophagus*
- ◆ 2,371 synonyms
  - *Orbit* has a synonym *Eye socket*
- ◆ Every concept has at least one *is-a* relationship
- ◆ 4% concepts have more than one *is-a* relationship
  - *Radius bone is-a Long bone*  
*is-a Bone of the upper extremity*
- ◆ Concepts are connected by a *part-of* relationship
  - *Liver is physical part of Gastrointestinal system*



# MA and NCI

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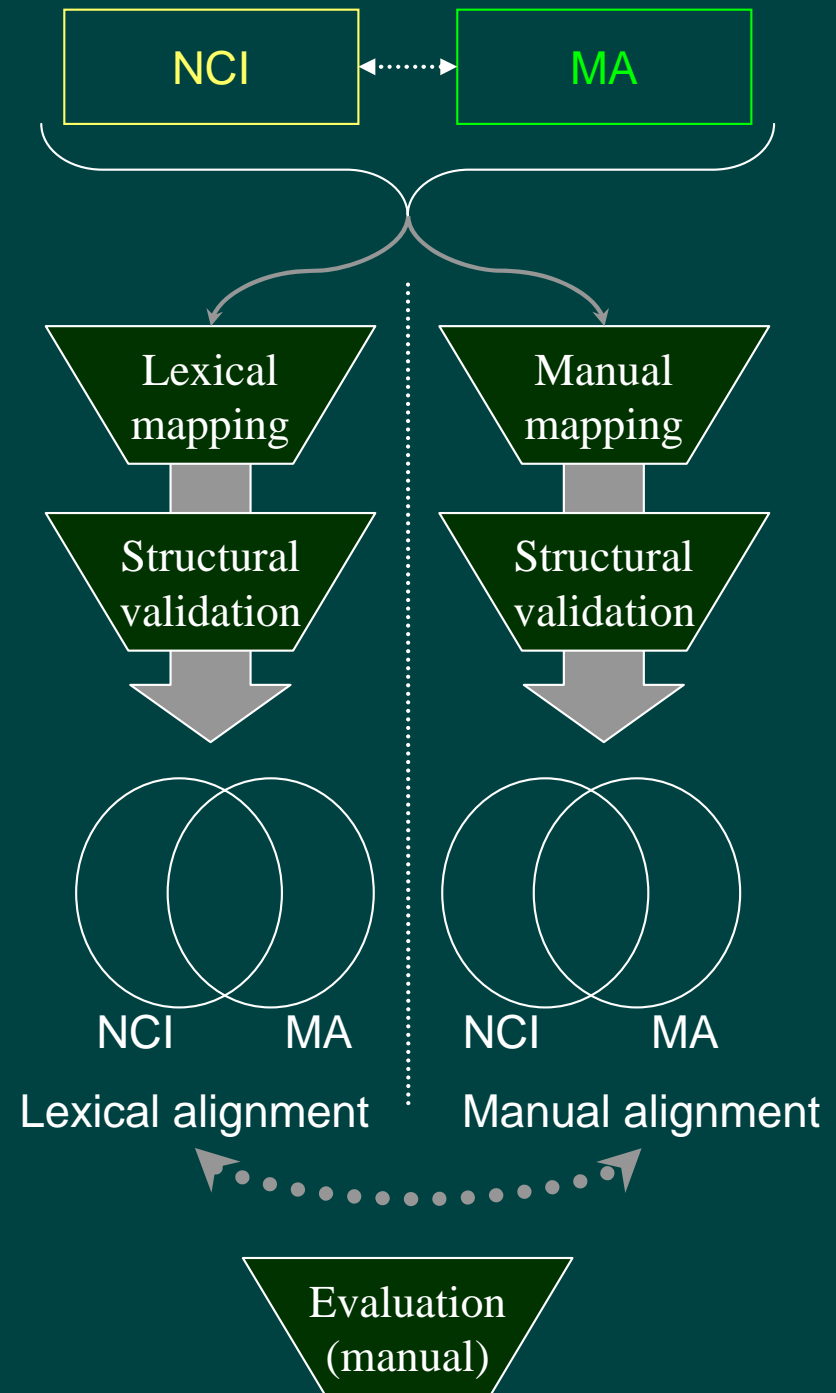
	MA	NCI
Underlying data model	Directed acyclic graph	Available in OWL
Domain coverage	Mouse anatomy	Human anatomy related to cancers
Concepts	2,404	4,410*
Synonyms	259	2,371
Hierarchical relationships	<i>is-a, part-of</i>	<i>is-a, part-of</i>
Inverses	-	-

\* Of which some 2000 correspond to entities not included in MA



# Methods

# Overview



# Lexical approach

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- ◆ Comparing two ontologies at the term level
  - Exact match
  - Match after normalization
- ◆ Preferred names and synonyms are used
  - MA: *Forelimb*  
NCI: *Upper extremity* (synonym: *Forelimb*)
- ◆ UMLS synonymy is used to identify additional matches
  - MA: *Profunda femoris artery*  
NCI: *Deep femoral artery*

# Manual approach



Search for

in these sections

- All sections
- Gene symbols/names
- Accession IDs

## Adult Mouse Anatomy

Term Detail

MA term: **forelimb**  
MA id: MA:0000025  
Number of paths to term: 1

① denotes an 'is-a' relationship  
② denotes a 'part-of' relationship

[mouse anatomy](#)

[adult mouse](#)

② [anatomic region](#)

① [limb](#)

① [forelimb \[MA:0000025\]](#)

② [arm](#) +

② [elbow](#) +

② [forelimb blood vessel](#) +

② [forelimb bone](#) +



National Cancer Institute

U.S. National Institutes of Health | [www.cancer.gov](http://www.cancer.gov)

Quick Search

forelimb

Max Results

100

Advanced Search

Information about this concept

Accepted\_Therapeutic\_Use\_For

Vocabulary: NCI\_Thesaurus

Concepts visited (during this session)

Upper Extremity

QUICK LINKS

[NCI HOME](#)

[NCICB HOME](#)

[EVS HOME](#)

[SITE HOME](#)

[KNOWN ISSUES](#)

[HELP](#)

[RESULTS](#)

[CUSTOMIZE](#)

[ABOUT](#)

[BROWSE HIERARCHY](#)

[LOGOUT](#)

### Concept Details

[Bookmark this page](#)



Upper Extremity

[Printable Page](#)

[History](#)

[Graph](#)

#### Identifiers:

name

Upper\_Extremity

code

C12671

#### Information about this concept:

Display\_Name

Upper Extremity

Synonym with source data

Forelimb|SY|CTRM

Synonym with source data

Upper Extremity|DN|CTRM

Synonym with source data

Upper Extremity|PT|CTRM

Synonym with source data

Upper Extremity|PT|NCI

Synonym with source data

Upper Limb|SY|CTRM

Preferred\_Name

Upper Extremity

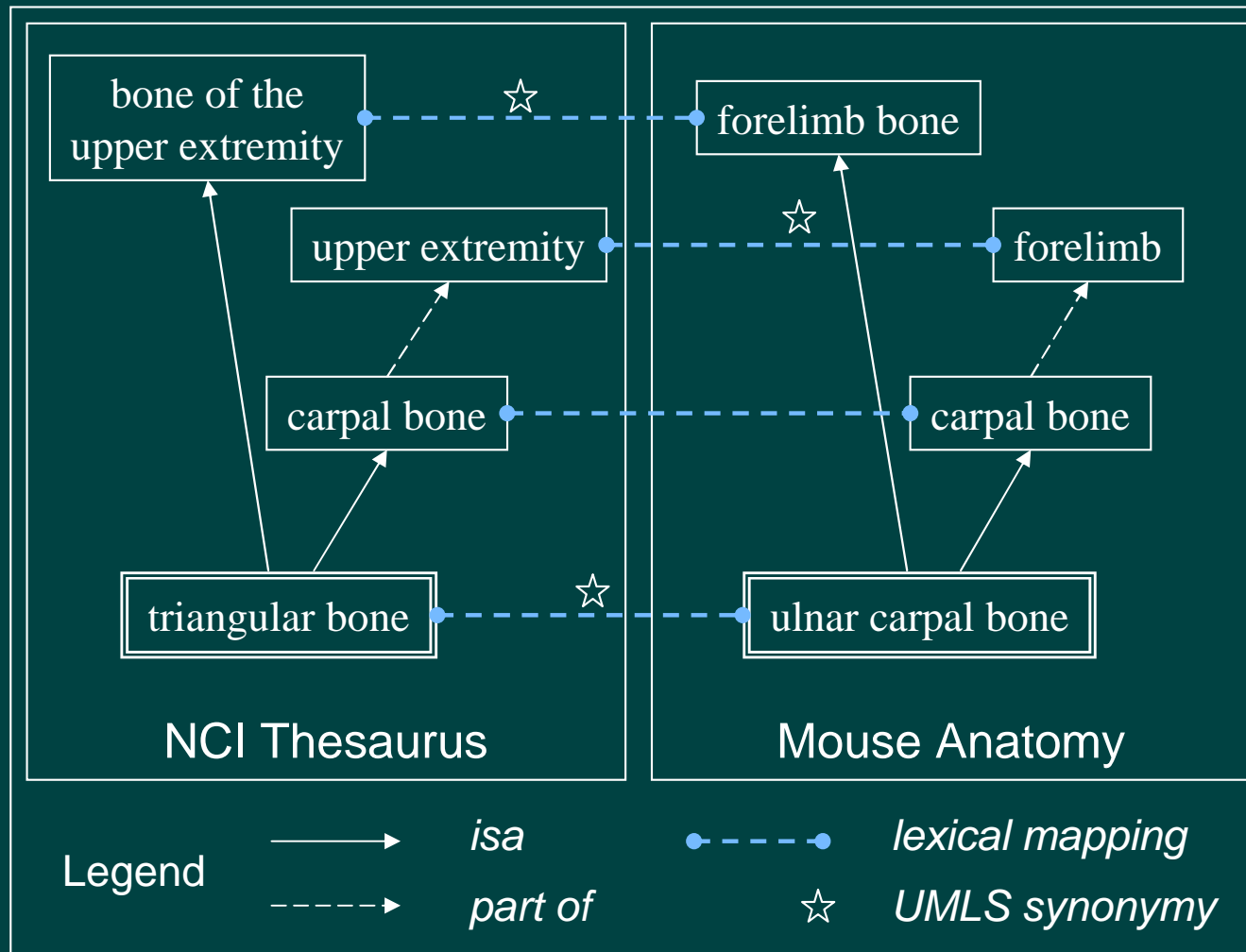
Semantic\_Type

Body Location or Region

Synonym

Forelimb

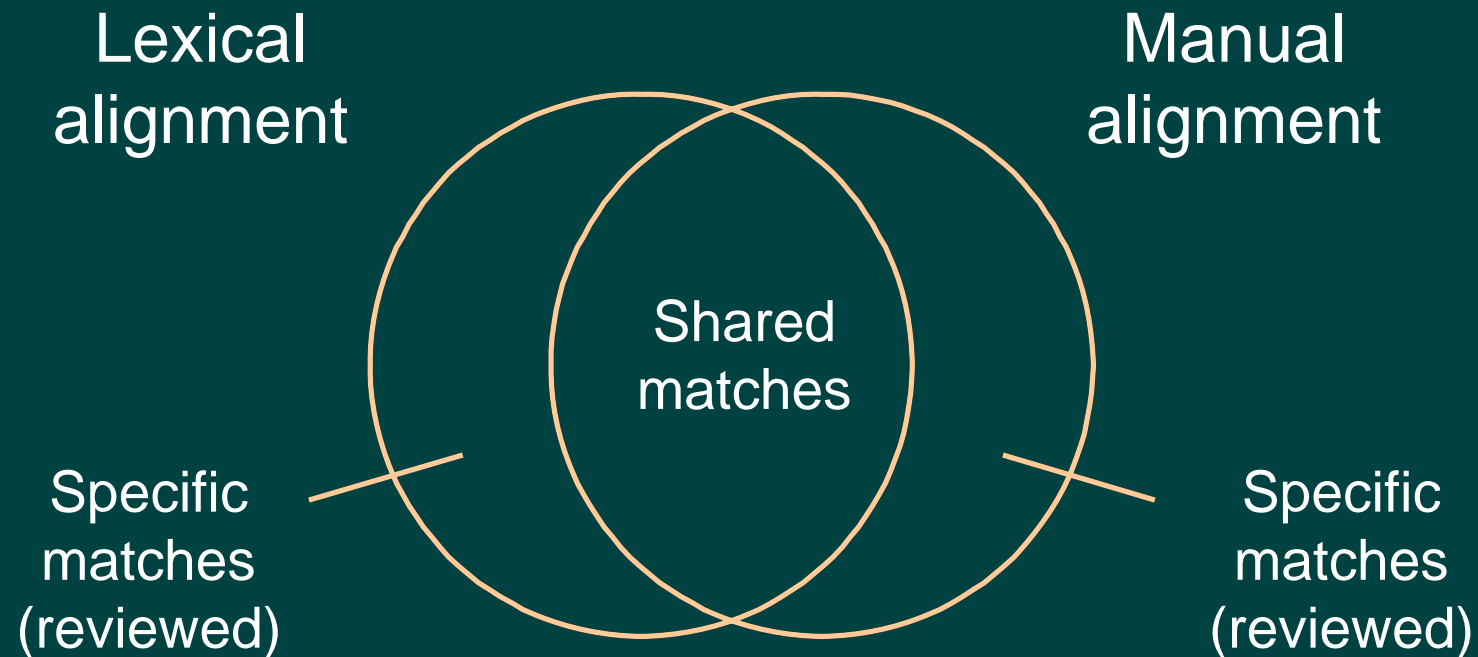
# Validation by structural similarity



- Uses relations explicitly represented in each system and transitive closures
- Presence of relations to other anchors interpreted as structural evidence

# Evaluation

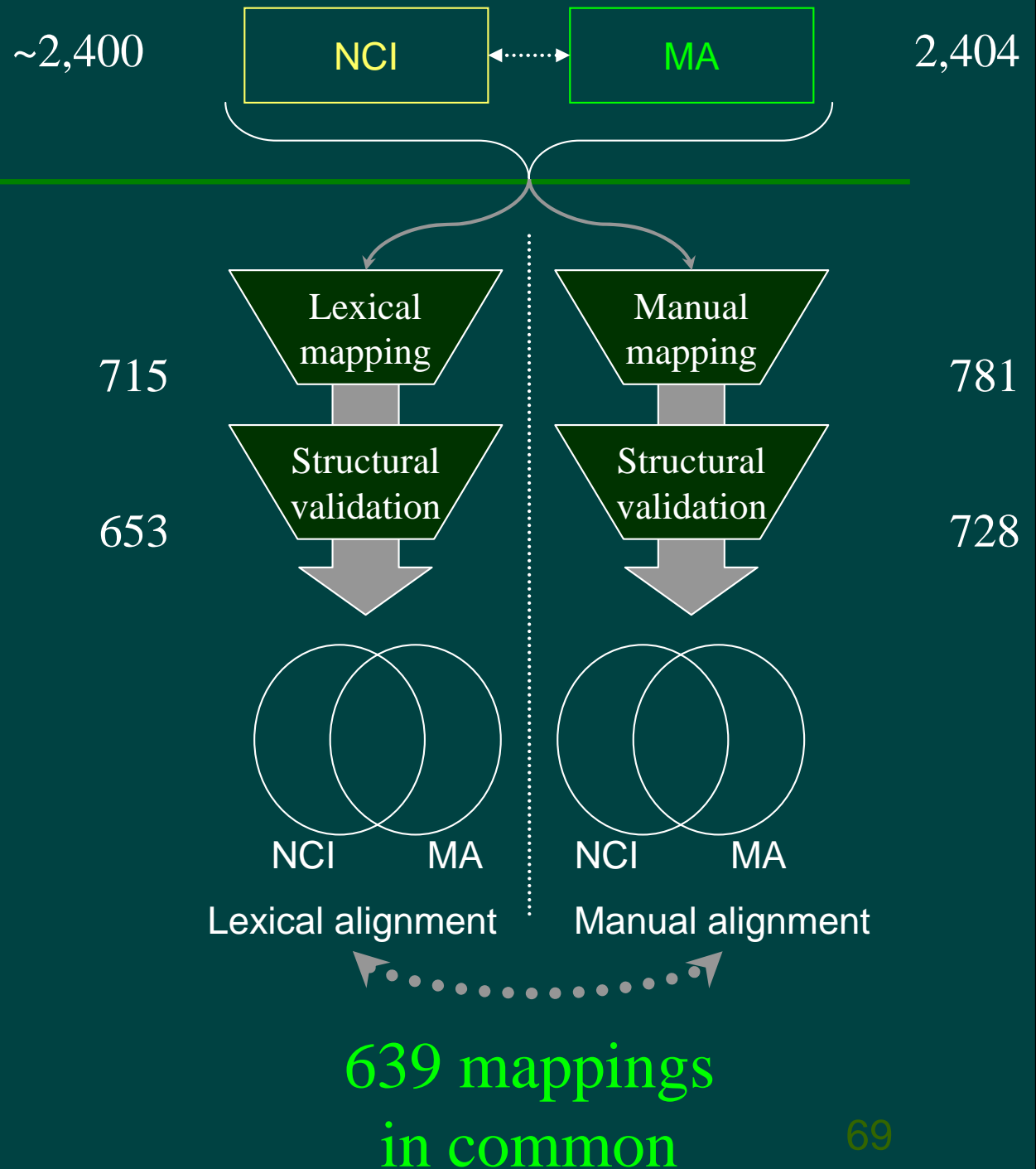
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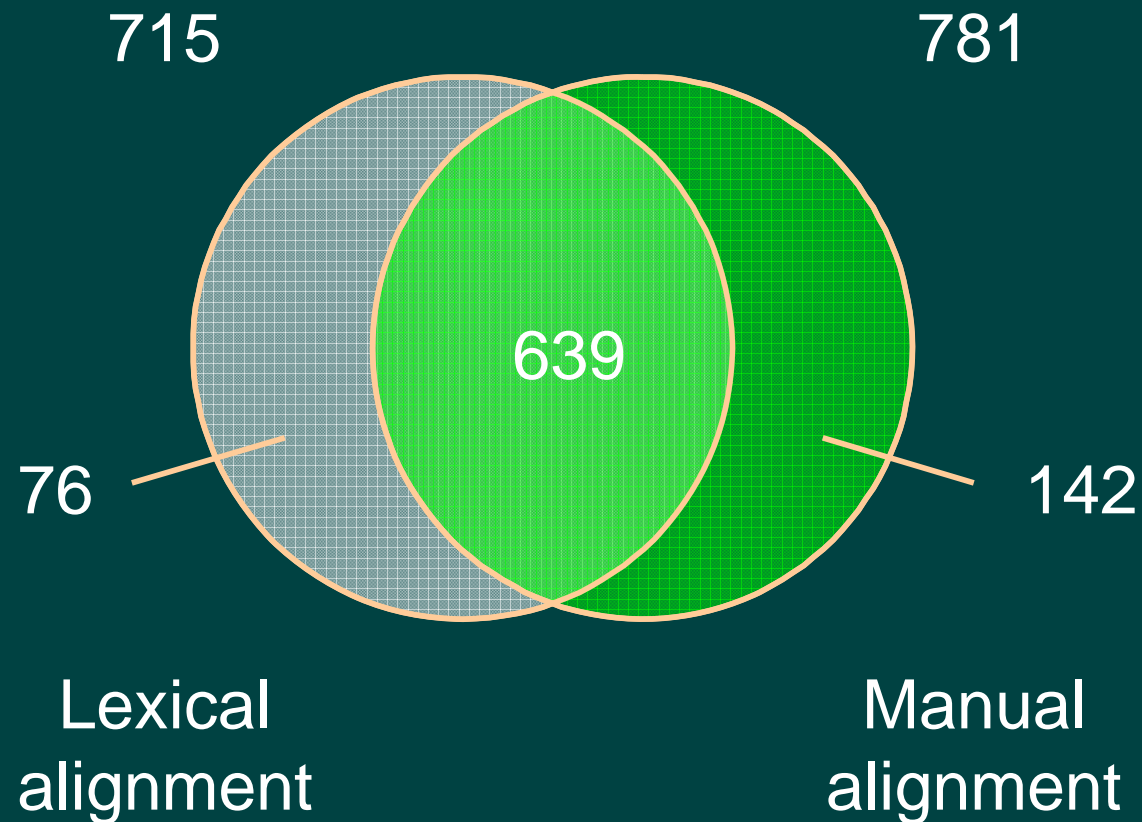
# Results

# Results



# Comparison of the two alignments

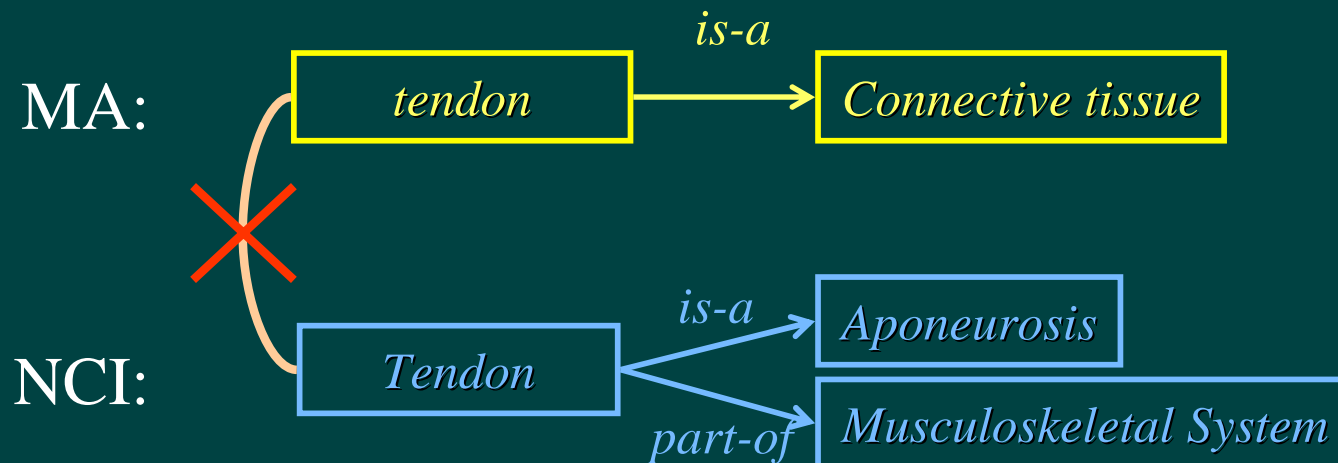
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# Mappings identified by both approaches

## ◆ 639 mappings identified by both approaches

- Most of them supported by structural evidence
  - {MA: *uterine cervix*, NCI: *Cervix Uteri*}
- Some not supported by structural evidence
  - {MA: *tendon*, NCI: *Tendon*}



# Mappings specific to the lexical approach

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- ◆ 76 mappings specific to the lexical approach
  - Benefited from using UMLS synonyms
  - 61 valid mappings (80%)
    - {MA: *lienal artery*, NCI: *Splenic Artery*}
  - 15 invalid mappings
    - {MA: *cerebellum lobule I*, NCI: *Lingula of the Lung*}

# Mappings specific to the manual approach

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- ◆ 142 mappings specific to the manual approach
  - 133 valid mappings (94%)
    - {MA: *alveolus epithelium*, NCI: *Alveolar Epithelium*}
  - 9 invalid mappings
    - Human errors (coding)

# Discussion

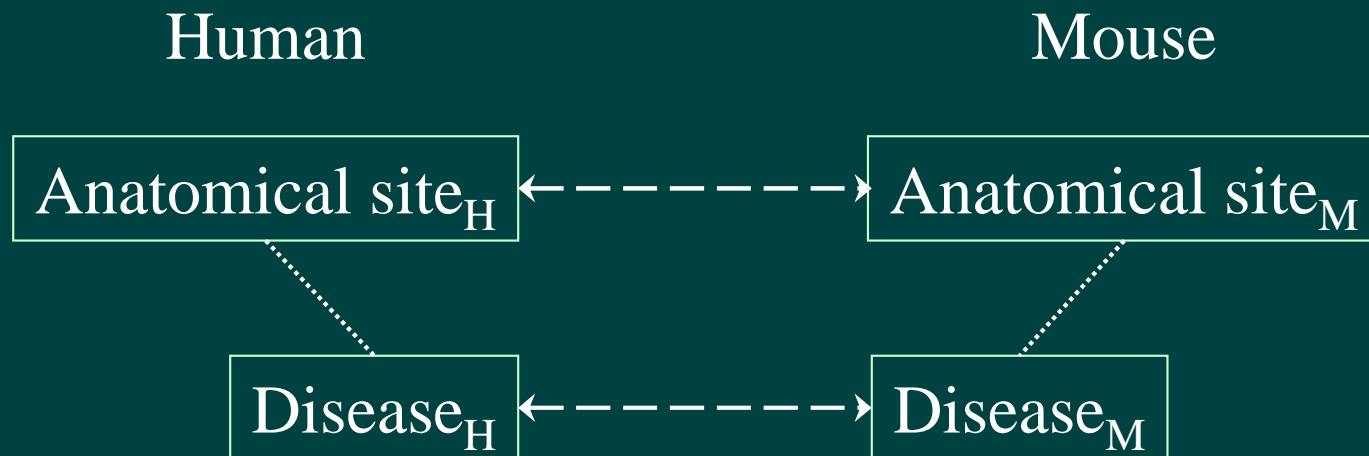
# Applications of the mapping for biologists

## ◆ Important for comparative science

- Mouse models of human diseases  
e.g., [emice.nci.nih.gov](http://emice.nci.nih.gov)



## ◆ Example





# Lessons learned

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## ◆ Curated mapping

- Only one expert

## ◆ Lexical approach

- Large proportion of valid mappings
  - Including among mappings not supported by structural evidence (conservative approach)

## ◆ Manual approach

- Can be supported by automated validation techniques (structural evidence), used to focus the attention of experts on potential problems

# References

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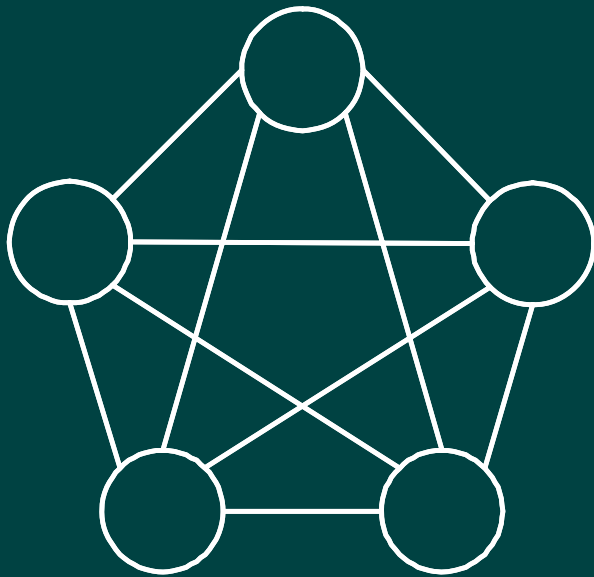
- ◆ Bodenreider O, Hayamizu TF, Ringwald M, de Coronado S, Zhang S. *Of mice and men: Aligning mouse and human anatomies*. Proceedings of AMIA Annual Symposium 2005:61-65.  
<http://mor.nlm.nih.gov/pubs/pdf/2005-amia-ob.pdf>



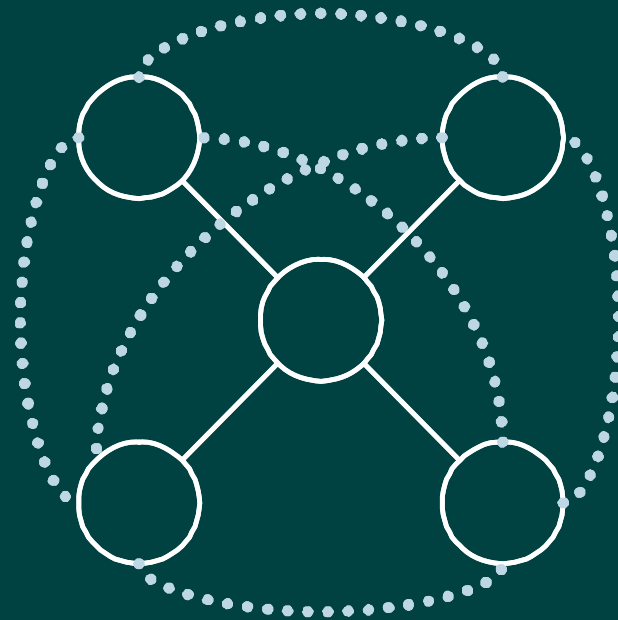
Indirect Alignment  
of Multiple Ontologies of Anatomy:  
through a Reference Ontology

# Approaches to aligning multiple ontologies

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Pairwise  
alignment

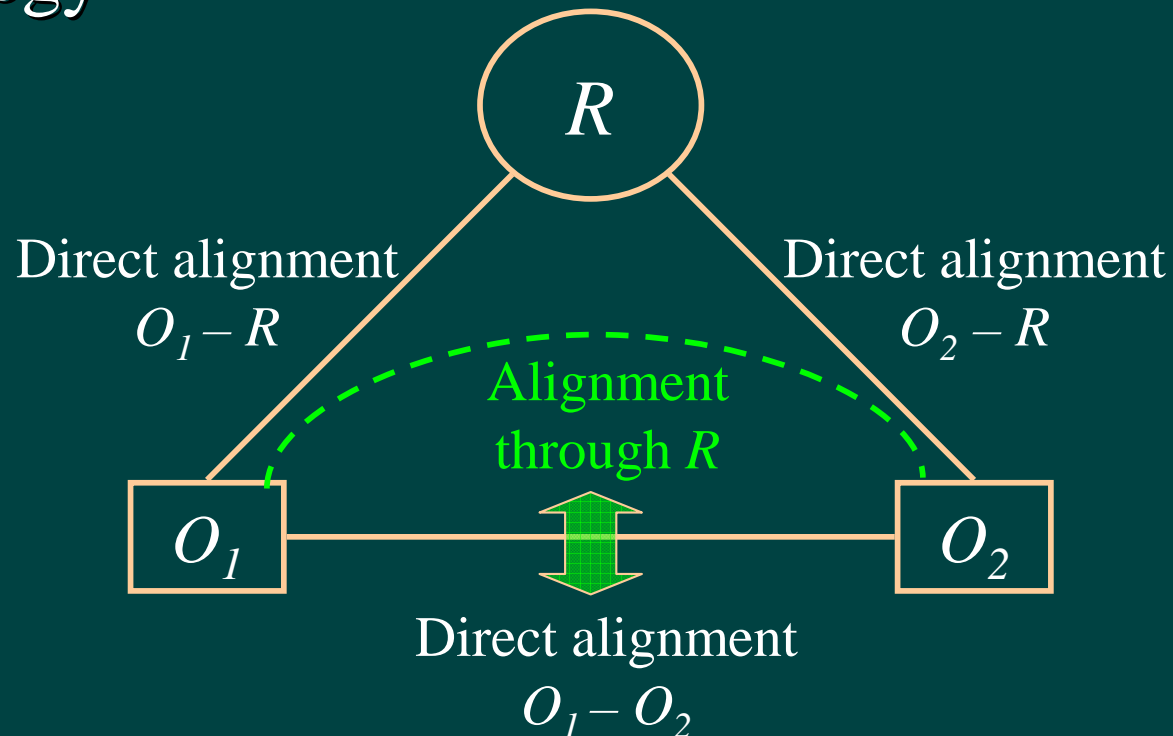


Alignment through  
a reference

# Introduction

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- ◆ Objective: to investigate the indirect alignment of two anatomical ontologies through a reference ontology



# Introduction

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- ◆ Three ontologies of anatomy:
  - Adult Mouse Anatomical Dictionary (MA)
  - Anatomy subset of NCI Thesaurus (NCI)
  - Foundational Model of Anatomy (FMA)
- ◆ First attempt to automatically derive mappings among ontologies from their alignments to a reference ontology

# Materials

# Adult Mouse Anatomical Dictionary

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- ◆ Structured controlled vocabulary
- ◆ 2,404 concepts each identified by one name
  - *Head/neck, Adrenal artery*
- ◆ 259 synonyms
  - *Limb* has a synonym *Extremity*
- ◆ Directed acyclic graph
- ◆ Two relationships: *is-a* and *part-of*
- ◆ 38% concepts have no *is-a* relationship
  - *Knee part-of Hindlimb*
- ◆ 4% concepts have more than one *is-a* relationship
  - *Hand phalanx is-a Phalanx*  
*is-a Hand digit bone*



# NCI Thesaurus

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- ◆ Standard vocabularies for cancer research
- ◆ Anatomy class
- ◆ Available in Ontology Web Language (OWL)
- ◆ 4,410 concepts, each having one preferred name
  - *Abdominal esophagus*
- ◆ 2,371 synonyms
  - *Orbit* has a synonym *Eye socket*
- ◆ Every concept has at least one *is-a* relationship
- ◆ 4% concepts have more than one *is-a* relationship
  - *Radius bone is-a Long bone*  
*is-a Bone of the upper extremity*
- ◆ Concepts are connected by a *part-of* relationship
  - *Liver is physical part of Gastrointestinal system*



# Foundational Model of Anatomy

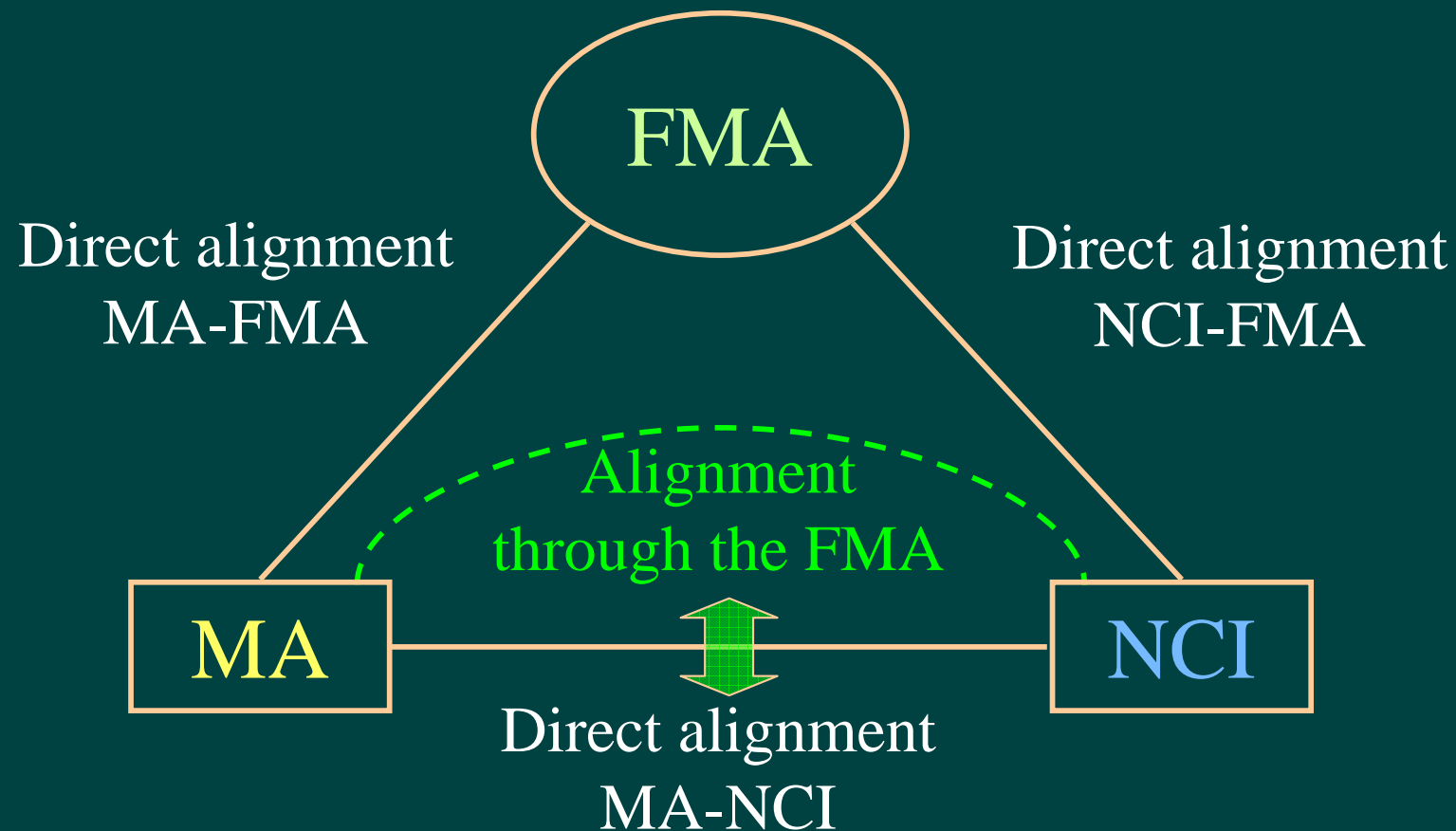
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- ◆ Conceptualize the physical objects and spaces that constitute the human body
- ◆ Frame-based structure in Protégé
- ◆ 71,202 concepts, each having one preferred name
  - *Uterine tube*
- ◆ 52,713 synonyms
  - *Uterine tube* has a synonym *Oviduct*
- ◆ Every concept has one and only one *is-a* relationship
- ◆ Seven *part-of* relationships and their inverses
  - *constitutional part of* and *constitutional part*
  - *regional part of* and *regional part*

# Methods

# Three phases

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# Phase 1 Direct alignment

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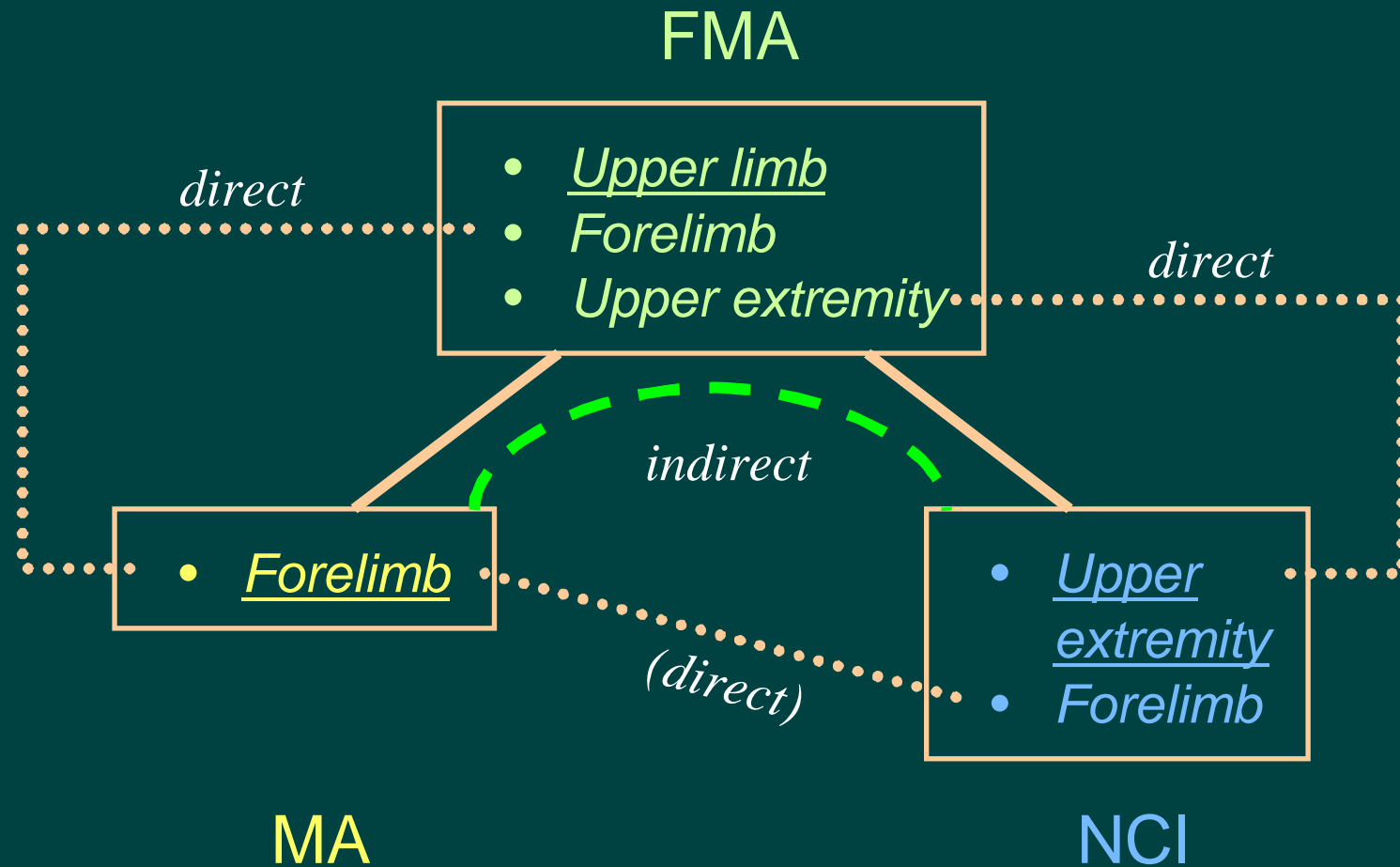
## Lexical alignment

- Acquiring terms
- Identifying matches (i.e., shared concepts) lexically

## Structural alignment

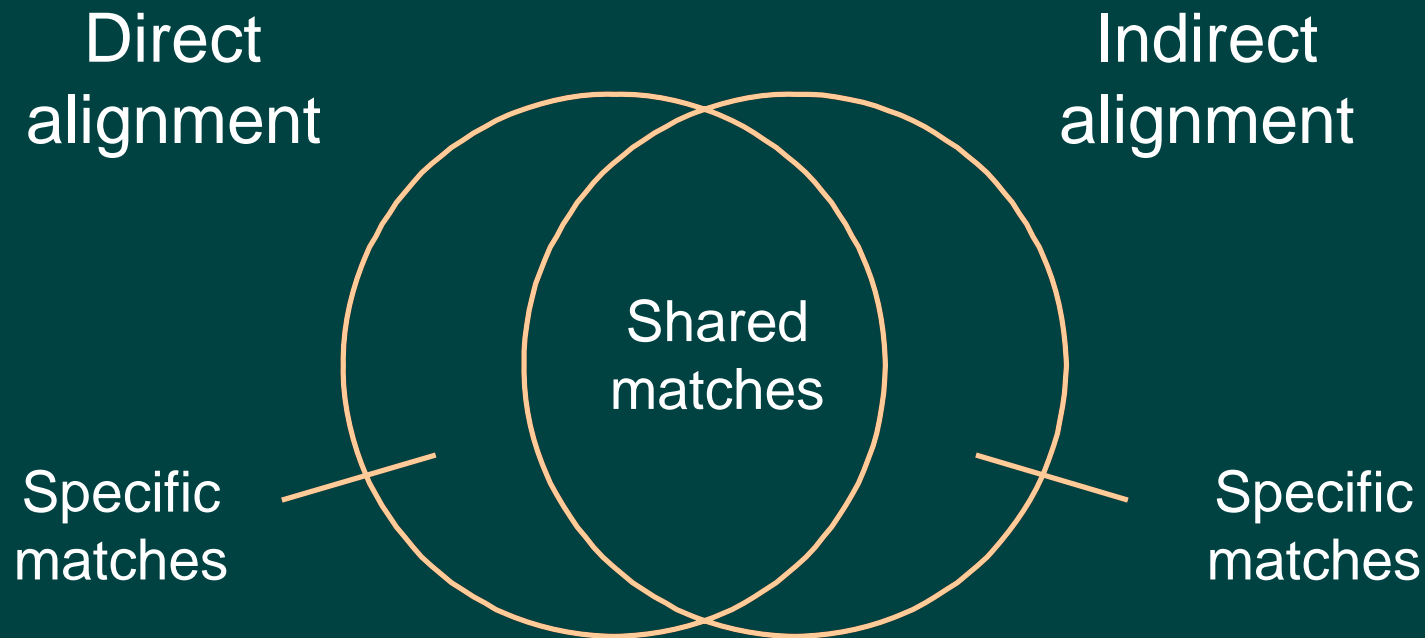
- Acquiring (explicit and implicit) semantic relations
- Identifying matches structurally

# Phase 2 Indirect alignment



# Phase 3 Comparison of two alignments

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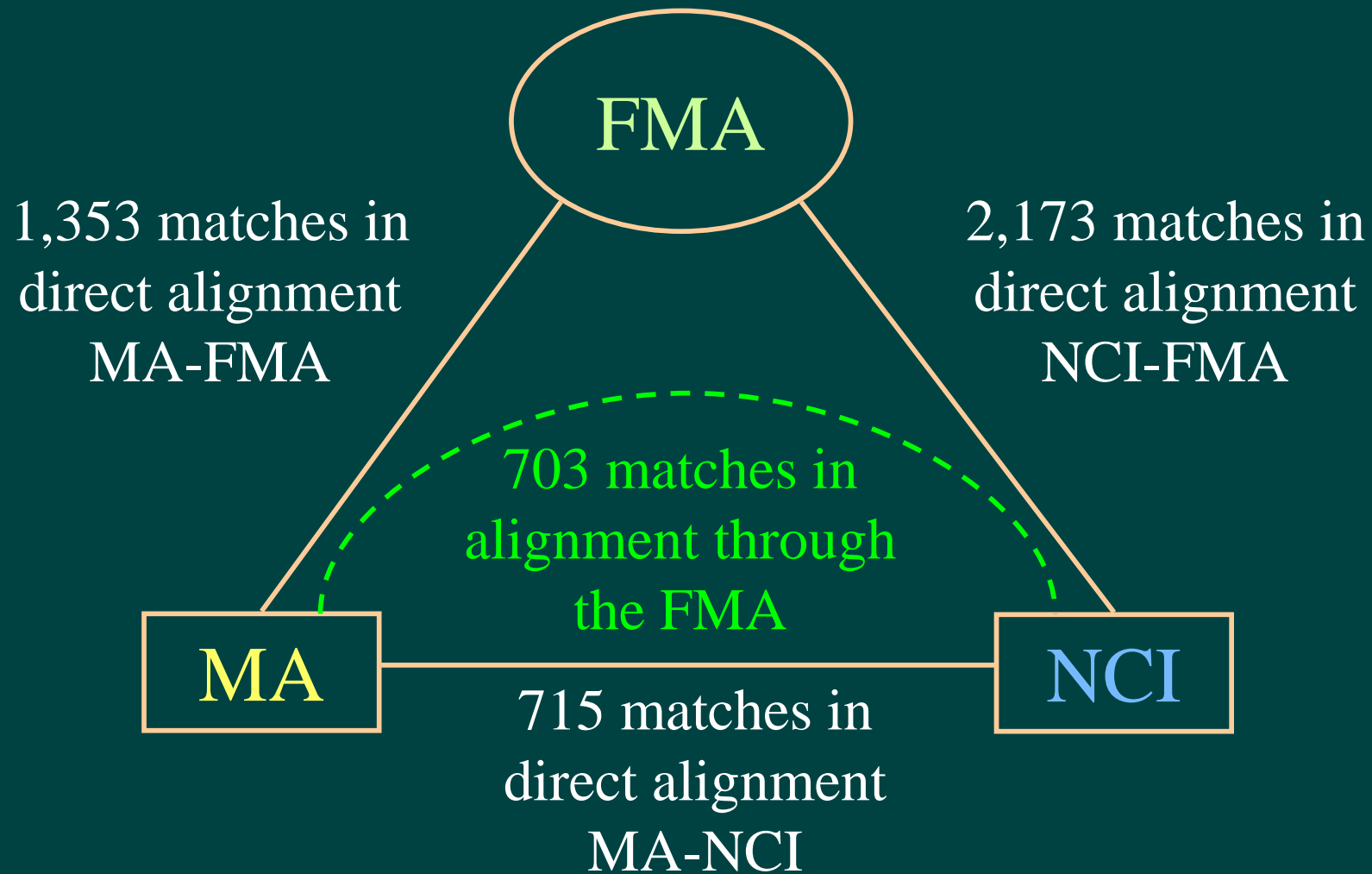


# Results



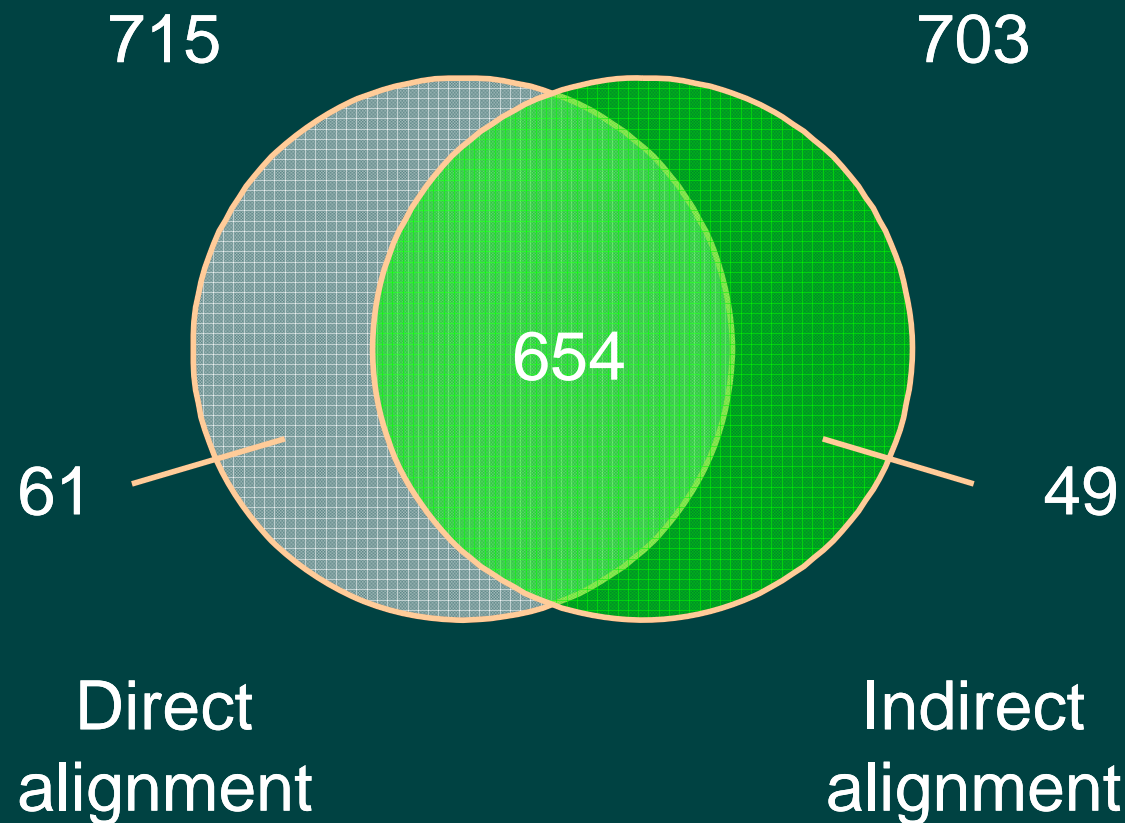
# Indirect alignment

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# Comparison of two alignments

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# Discussion

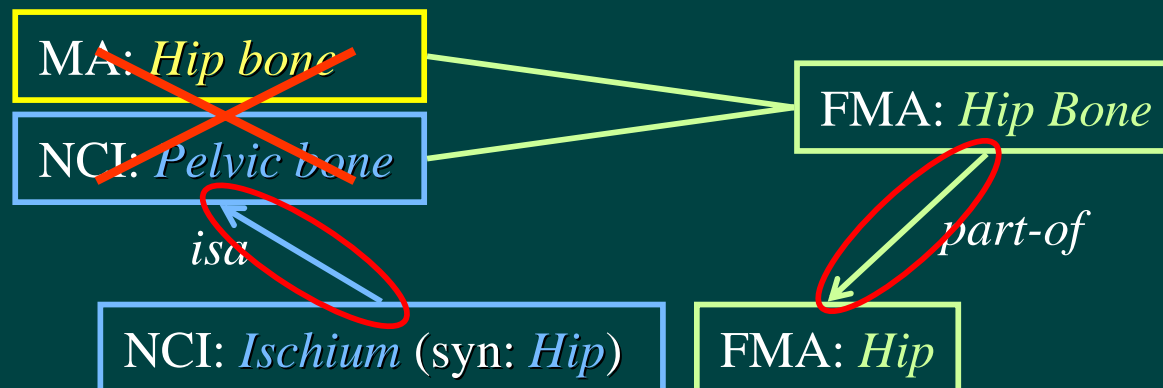
# Benefits of the indirect alignment

## ◆ Why are the 49 matches not identified in the direct alignment?

- Additional synonyms by the FMA

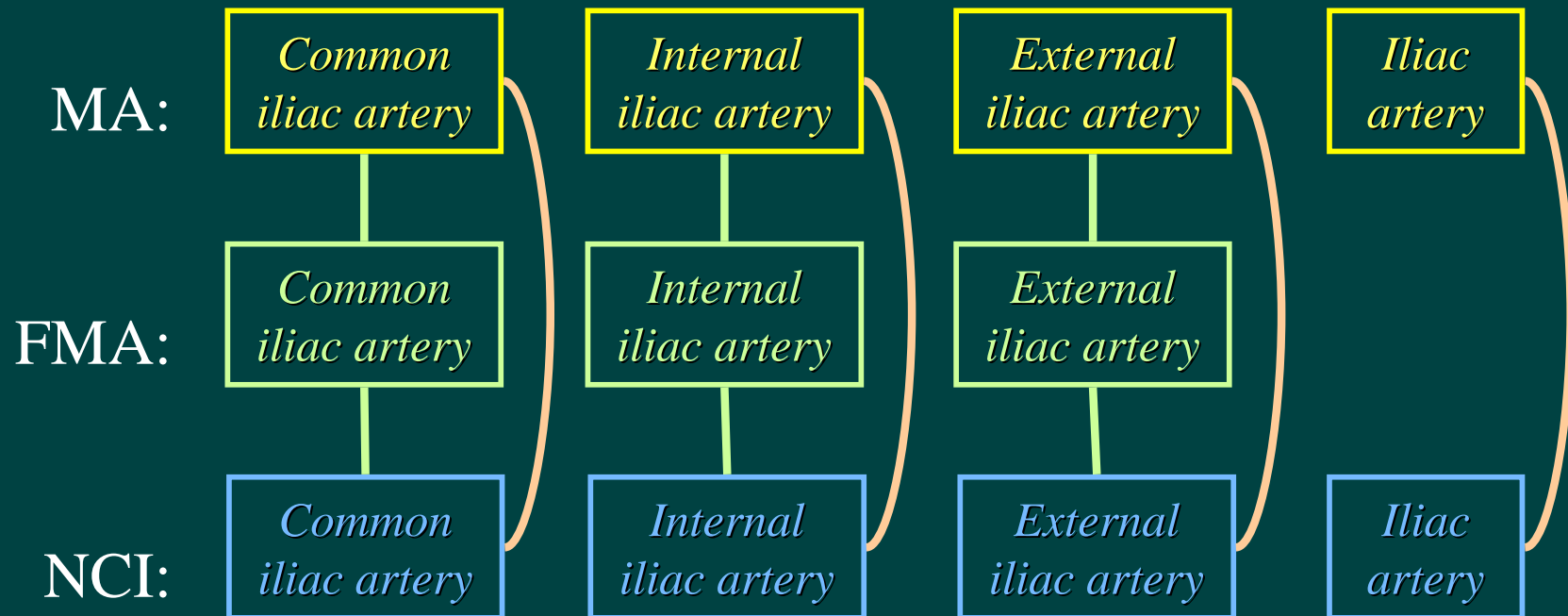


- Additional relations by the FMA



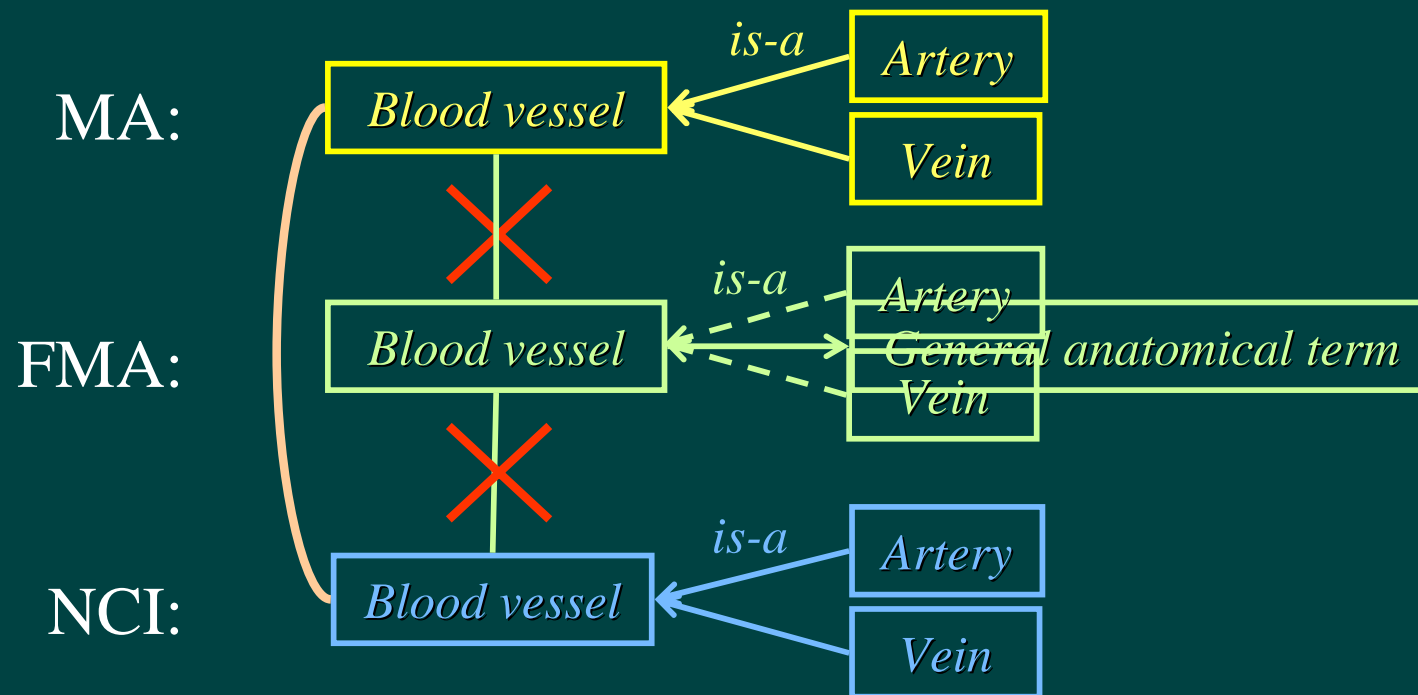
# Benefits of the direct alignment

- ◆ Why are the 61 matches not identified in the indirect alignment through the FMA?
  - Different coverage



# Benefits of the direct alignment

- ◆ Why are the 14 matches supported in the direct alignment while having no evidence in the indirect alignment through the FMA?
  - Different representation

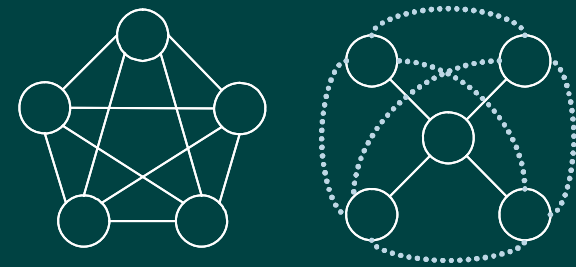


# Alignment through a reference vs. pairwise alignment

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## ◆ Efficiency of alignment through a reference

- $n(n-1)/2$  pairwise mappings
- $(n-1)$  mappings to a reference



## ◆ Feasibility of alignment through a reference

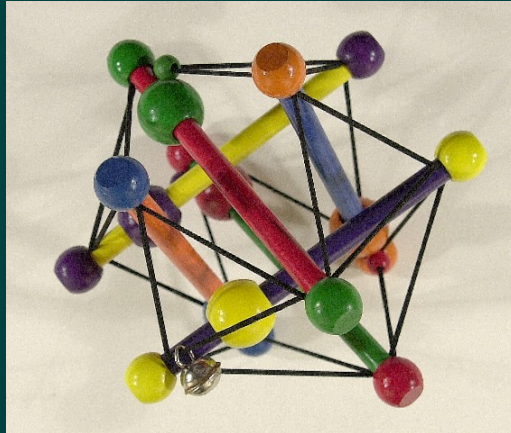
- Identified 91% of matches in the direct alignment
- Identified additional matches not discovered by the direct alignment
- Validated the FMA as a reference ontology

# References

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- ◆ Zhang S, Bodenreider O. *Alignment of multiple ontologies of anatomy: Deriving indirect mappings from direct mappings to a reference.* Proceedings of AMIA Annual Symposium 2005:864-868.  
<http://mor.nlm.nih.gov/pubs/pdf/2005-amia-sz.pdf>





# Medical Ontology Research

Contact: [olivier@nlm.nih.gov](mailto:olivier@nlm.nih.gov)

Web: [mor.nlm.nih.gov](http://mor.nlm.nih.gov)



*Olivier Bodenreider*

Lister Hill National Center  
for Biomedical Communications  
Bethesda, Maryland - USA